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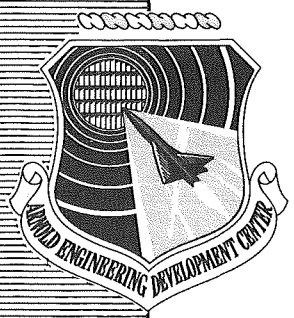

DIFFUSION PUMP BAFFLE STUDY

By

M. H. Hablanian

NRC Equipment Corporation

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(Prepared under Contract No. AF 40(600)-1009 by NRC Equipment Corporation, Newton Highlands, Massachusetts)

ARNOLD ENGINEERING DEVELOPMENT CENTER

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November 1964

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FOREWORD

This report covers the period from 30 July 1962 to 20 April 1964. This research program was performed under contract AF 40(600)-1009 dated 30 July 1962. The objective of this work was to develop and check performance of an optimum oil diffusion pumping station, having maximum pumping speed consistent with the requirement for minimum backstreaming, for use on a large space environmental chamber.

The project was monitored by Capt. G. Mushalko and Mr. Ross Roepke of the Technology Division, DCS/Plans and Technology, Arnold Engineering Development Center, Arnold Air Force Station, Tennessee.

Research, design, fabrication, and test were conducted at NRC Equipment Corporation, Newton Highlands, Massachusetts, under the direction of Mr. M. H. Hablanian.

Data reported here are recorded in NRC Equipment Corporation research notebooks No. 15, 23, 24 and 50.

ABSTRACT

This study was undertaken to develop and test a diffusion pumping station having maximum pumping speed consistent with minimum backstreaming for use on a large space environmental chamber. The complete system includes pump, duct, and baffle. Conductance measurements were made using small-scale model ducts and baffles to determine the most promising configuration for the full-scale system. As a result of this preliminary work, a 52" diameter liquid nitrogen cooled baffle was developed which has a transmission probability of 0.35 while the reducer duct-baffle combination developed retains 50 per cent of the pumping speed above the baffle. Backstreaming measurements ranged from 7.3×10^{-7} mg/cm^2-min for a short duration test (63 hours) to 7×10^{-8} mg/cm^2-min for a long duration test (524 hours). Along with the backstreaming measurements, the residual gas composition in the test dome was checked with a mass spectrometer residual gas analyzer.

A lesser aspect of this study was to compare the backstreaming rates of two diffusion pump oils above a liquid nitrogen cooled baffle. The baffle was constructed to approximate the full-scale 52" baffle. DC-705 had a slightly higher backstreaming rate than Convalex 10, but somewhat lower ultimate pressures were obtained with the DC-705.

PUBLICATION REVIEW

This report has been reviewed and publication is approved.

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I. INTRODUCTION

This report describes an experimental study for the design, construction and test of an optimum diffusion pumping station employing a 35" pump. Model studies were performed to obtain the optimum duct-trap combination. Following this a major effort was expended in evolving an optimum design of a liquid nitrogen cooled baffle for the 35" diameter, 50,000 l/s oil diffusion pump, and measuring the backstreaming rate above this baffle.

In addition, the residual gas composition in the test dome was checked with a mass spectrometer gas analyzer and backstreaming rates of two diffusion pump oils were compared.

Oil diffusion pumps are used in almost all large space simulation chambers for obtaining pressures in the high and ultrahigh vacuum range. One of the most significant advantages is their ability to handle relatively high gas loads. In addition, modern diffusion pumps retain their pumping speed at pressures as low as 10^{-14} torr. This has been recently demonstrated (for helium), for example, in the extreme high vacuum facility at NRC[1] and in our laboratory[2].

Of course, the pump can also be a source of gas and, in the case of oil diffusion pumps, the backstreaming and backmigration of the pumping fluid and its breakdown products into the vacuum system is of particular importance. A variety of baffles and traps has been used to reduce the amount of such products, which are generally hydrocarbons, reaching the vacuum chamber from the pump. With partial pressure measurements, it can be shown that in a baked all-metal or glass ultrahigh vacuum system the hydrocarbons with molecular weight higher than 25 can be kept near or below 10^{-13} torr[2].

The basic requirement in designing diffusion pump baffles is the interception of all direct lines of sight between the inlet and the outlet of the baffle. In the molecular flow range this assures that practically all molecules entering the baffle from any direction must have at least one collision with the baffle surfaces. The warmest part of such baffle surfaces should be kept at the temperature which assures very high sticking probability and a negligible vapor pressure for trapped oil molecules.

If the outer walls of the baffle are not cooled, creep barriers can be used to prevent the possibility of molecules bypassing the baffle near the outer wall and the possibility of creep on the surface of the outer walls.

The effectiveness of single collision baffles depends on the manner of flow of the backstreaming oil. The number of collisions between backstreaming oil molecules should be negligible to avoid other than straight line trajectories inside the baffle.

A water-cooled baffle placed between the pump and the refrigerated baffle should provide the latter requirement. In addition, a water-cooled baffle helps to return the condensed oil back into the pump. However, recent evidence indicates that the primary backstreaming rate of modern diffusion pumps may be sufficiently low to satisfy the requirement of straight line trajectories. For example, when objects are placed in a dome directly above the pump, they produce sharp shadows even after weeks of operation[3]. This is particularly true when cooled caps are used around the top nozzle of the pump. In addition, the collection of oil on the liquid nitrogen trap will be further reduced if the trap is placed at a distance above the pump equal to about 1/3 of the pump diameter[4] without serious sacrifice of conductance.

The same effect can be achieved by the use of only partial baffles around the periphery of the inlet duct knowing the source and the distribution of primary backstreaming. Recent experiments using the "pin-hole" camera technique clearly demonstrate that the major source of backstreaming is the immediate vicinity of the top nozzle, even when cold caps are used[4,5].

Some common baffle or trap configurations are shown in Fig. 1 schematically. One can optimize the conductance of such arrays by selecting the best angles, best width-to-height ratios, etc. However, there are other aspects which must be considered before a selection of the best baffle design can be made for a particular vacuum system. Some of these aspects are listed below:

1. The method of attachment of the pump to the vacuum chamber. This can provide a choice between elbow or in-line baffles.

2. Other structural considerations which may dictate the shape (particularly the length and diameter) of the inlet ducts.

3. Liquid nitrogen consumption (or other refrigeration requirement). In general, higher conductance is associated with higher consumption.

4. Temperature, manner of cooling, and temperature uniformity of the baffle surfaces.

5. Presence or absence of internal (liquid nitrogen) reservoirs.

6. Average number of collisions with the cold surfaces for molecules passing through the baffle. Sometimes better trapping may be preferable to higher conductance. For example, Fig. 1A has some redundant surfaces for a single collision baffle which are eliminated in the other designs shown in Fig. 1. Fig. 1B is known to have considerably higher conductance than Fig. 1A.

7. Presence of creep barriers. Some designs are more adaptable than others for inclusion of creep barriers.

8. Desirability of removing the baffle members from their enclosure for cleaning, repairs or other reasons.

9. Leak-proof construction. The number of joints in the cooling passages should be minimized to reduce potential leak or outgassing sources.

10. Length of operation without interruption.

11. Presence or absence of a water-cooled baffle used in conjunction with a liquid nitrogen cooled baffle.

12. Start-up and shut-off procedure of the pump-baffle combination, particularly in systems which do not have a high vacuum valve.

13. Baking and cooling procedure of the vacuum chamber and the baffle.

14. Ease of fabrication and assembly which, together with size and material choices, determine the cost of the baffle.

15. The degree of accumulation of pump oil in the baffle and the manner of flow of draining oil during defrosting.

It is obvious that many alternate arrangements are possible and design compromises must be made according to the particular system requirements.

Fig. 2 illustrates the choice between higher conductance and lower liquid nitrogen consumption. Design A, having less projected area than B, will use less liquid nitrogen, but B has much higher conductance. The same is true comparing designs C and D. (Refrigerated surfaces are shown with heavy lines.)

Obviously, the requirement of thorough trapping is not compatible with the desire to retain the highest possible pumping speed. The conventional arrangement of a water-cooled baffle followed by a liquid nitrogen trap, usually retains only 25 to 30% of the available pumping speed. During the work described in this report, an attempt was made to design and evaluate a single baffle cooled by liquid nitrogen which would retain at least 50% of the pumping speed.

An extensive study of various baffle geometries (both theoretical and experimental) has been made by Levenson, Milleron and Davis[6]. Their experimental procedure for conductance measurements was essentially the same as used in our work, and consisted of comparing conductances of various baffles to those of orifices of known dimensions.

When a diffusion pump is used with an "optically tight" baffle the rate of backstreaming above such a baffle is so low that it is impossible to measure it by the usual collection method (American Vacuum Society Tentative Standards). Among the more sensitive methods is the use of mass spectrometers which have been recently adapted for residual gas analysis in high vacuum chambers. During initial phases of this project the mass spectrometry measurements were intended to be the main method for monitoring the rate of backstreaming above the liquid nitrogen cooled baffle. However, subsequent work revealed the difficulty of correlating the ion currents indicated by the mass spectrometer with the amount of backstreaming pumping fluid, and the emphasis was shifted to direct gravimetric measurements.

It may be reasonable to expect that the amount of backstreaming can depend on the type of pumping fluid used in a pump of given design and power input. The backstreaming rate should depend on the density of the vapor jet issuing from the top nozzle. This, in turn, depends on fluid properties such as heat of vaporization and the vapor pressure. To check the possibility of significant differences, comparative tests with two pump fluids (DC-705 and Convalex-10) were performed in a special system using a 6" diffusion pump and baffle similar to the full-scale 35" pump station.

II. CONDUCTANCE MEASUREMENTS OF DUCT AND BAFFLE MODELS

A. GENERAL

The experimental arrangement for conductance measurements is shown schematically in Fig. 3. Inside the chamber there is a turntable which can hold six baffle models and each model can be indexed into position above the diffusion pump. The pump (NRC HS6-1500) has 1500 l/s pumping speed when measured in the usual manner. A Teflon O-ring below the turntable prevents bypass of the gas which is introduced into the chamber to obtain conductance values. The ionization gauges were calibrated against a secondary standard gauge which, in turn, was calibrated against a McLeod gauge in a special calibration system.

The absence of gross errors was proved by operating the system with orifices of various sizes in place of baffle models. The conductance values obtained for orifices between 1 and 3 inches diameter were in accordance with theoretical predictions with errors not exceeding ± 5%.

The conductance C was measured according to the usual definition

$$Q = C\,(p_1 - p_2)$$

where Q is the amount of gas flowing through the orifice (throughput) and p_1 and p_2 are pressures above and below the orifice.

The residual pressures existing in the two chambers when the gas inlet is shut off (p_{o1} and p_{o2}) were subtracted from the pressure values to obtain a correction at pressures near the ultimate. To avoid errors due to the condition of the ionization gauges when changing from one series of baffle models to another, a reference orifice was included in each setup. This also provided an opportunity to normalize the data directly by using ratios of conductances instead of computing their actual values. The reference orifice was always equal to the diameter of the baffle exit. In this way a transmission factor (or transmission probability) can be used which depends only on baffle geometry, and is independent of its size. The experimental results yield this transmission factor directly as follows:

$$\mathbf{p} = \frac{C}{C'} = \frac{p_1' - p_2'}{p_1 - p_2}$$

where superscript refers to the reference orifice.

B. EXPERIMENTAL MEASUREMENTS

The first series of tests were made with circular orifices in order to calibrate the system. Five orifices ranging from 1/2" to 4" diameter cut in 0.010" thick stainless steel plates were used. The sixth position on the rotating disk was covered with a blind plate to determine the amount of leakage other than through the orifice which is in the operating position. All places of possible leakage were taped with a special electrical insulation tape known to have a low outgassing rate.

The measurements were conducted in the 10^{-4} to 10^{-6} range using previously calibrated ionization gauges and controls. Four ionization gauge tubes have been calibrated together with four ionization gauge controls. The gauge tubes were NRC 553 Bayard-Alpert type, and the gauge controls were NRC Type 763.

The calibration was performed with a 6" diffusion pump system having a liquid nitrogen trap and a 6" diameter dome with three symmetrically located gauge positions. Two gauges were calibrated at a time by comparing their response with a secondary standard NRC 507 gauge tube which had been previously calibrated against a precision McLeod gauge[7].

The calibration gas was nitrogen. It was introduced into the system through a valve below the liquid nitrogen trap. The system was evacuated to about 5×10^{-8} torr, then backfilled with nitrogen and the calibration performed in the 10^{-6}, 10^{-5} and 10^{-4} torr ranges.

The gauge controls were checked for accuracy of output voltage and meter reading ($\pm$ 1%) and the accuracy of filament emission regulation ($\pm$ 1%).

The results of the measurements using the circular orifices are shown in Fig. 4 and Fig. 5. The first shows conductances plotted against pressure for each orifice; the second shows variation of conductance with orifice area. The conductances were computed according to $Q = C (p_1 - p_2)$. The gas flow Q (throughput) was measured with an oil manometer as usually employed for measurement of pumping speed.

The results are in good agreement with theoretical expectations. The deviation from a straight line in Fig. 4 is due to the increase of conductance at higher pressures near transition range from molecular to viscous flow. In addition, the inlet and discharge chamber geometry begin to have an effect on the conductance of the larger orifice. This demonstrates that the accuracy of the measurements becomes poor above orifice diameters of 3 inches for this system or, in other words, above conductance values of about 500 l/s.

Before this fact was clearly established, the conical baffle shapes were made with the exit diameter of 4", and were installed in the chamber. The measurement with the conical shapes indeed revealed this fact. The conductance differences between the cones having various D/D_o and L/D_o ratios were too small to be measured with sufficient accuracy.

To improve the accuracy of the measurements, the baffles were made smaller, keeping the conductances below approximately 500 l/s. This gave a higher pressure difference. In addition, the baffle used above the diffusion pump was removed to obtain more than twice the pumping speed below the models.

Figures 6, 8 and 10 show the configurations of the various models in the form of conical sections, elbow geometries and five chevron arrangements.

The graphs of Figs. 7, 9, and 11 show the measurements in the form of experimental transmission probability values plotted against the inlet pressure.

Figs. 6 and 7 show results with conical sections which may serve as transition pieces between the diffusion pump and a wider inlet duct.

The actual dimensions were chosen so as to make the comparison with theoretical predictions more convenient. The theoretical predictions for the molecular conductance of a frustum have been performed at AEDC using Monte Carlo analysis [8]. The deviation of data points from straight horizontal lines can be explained by inaccuracies in throughput and pressure measurements. However, since relative values are of greater interest and a calibrating geometry (orifice) has been included in each series of tests, the results are very useful for establishing the configurations and dimensions of the final inlet duct and baffle arrangements.

The experimental setup appears to have sufficient reproducibility and sensitivity to reveal at least 10% differences in conductance. For careful selection of optimum baffle geometry, it may be possible to reduce the uncertainty to 5% by repeating the tests several times, and by interchanging baffle positions on the multistation disk.

Fig. 9 shows results obtained with the elbow shapes which are shown in Fig. 8. The two identical geometries (8d and 8e) were included simply as a check of possible effects of inlet pressure distribution. Of interest is the comparison among the 8a, 8b, and 8c geometries. Fig. 8a is not an optically tight elbow. Fig. 8b has the same dimension as Fig. 8a, but is optically tight by virtue of the eye-shaped insert. Another

means of making 8a optically tight is to lengthen the legs, e.g., Fig. 8c. Both 8b and 8c are optically tight but 8b has 15% more conductance.

Figs. 10 and 11 show results obtained with various circular chevron geometries. The selection here was perhaps not as fortunate, since the differences are rather small. All that can be said is that 10b and 10ehave somewhat less conductance than 10c and 10d.

Additional series of conductance measurements were performed to obtain another check on the transition section between the baffle and the pump, and to check the conductance of diagonally arranged circular chevron baffles and compare them to more conventional chevron geometries. The main advantages of such baffles are larger area passages between individual "chevron" plates and removal of redundancy of conventional chevron configurations (see Fig. 10e).

Fig. 12 shows the results of conductance measurements of various reducers. The cylindrical short pipe and a 3" orifice were used for checking. The probability value of 0.57 for the pipe compares well with the value of 0.58 obtained by Clausing and Levenson[9]. There appears to be little difference between a conical reducer (Fig. 12a) and a straight reducer (Fig. 12b), the value being very close to 0.9. The difference between the other pair of reducers (Figs. 12c and 12d) is probably due to an experimental error. Fig. 12c may have had an internal leak outside of the main passage, explaining the somewhat higher value.

Fig. 14 shows the results obtained with the three chevron type baffles and two elbows shown in Fig. 13. One of the elbows from previous tests and a 3" orifice were used as checks.

The probability value of 0.265 for the elbow with the eye-shaped baffle (Fig. 8b) is somewhat higher than previously obtained 0.23. The second elbow with a 2-piece baffle (Fig. 13e) produced 0.28. The two circular chevron baffles produced highest probability values for an optically tight baffle structure. The baffle with five conical pieces and the central circular plate (Fig. 13a) produced 0.35 and the baffle with the four conical pieces 0.33 transmission probability. Those values compare very well with values obtained by Levenson et al on straight cylinders with two restricted ends and circular blocking plate[6]. For L/R_o of 2.67 and R/R_o of 1.29, as used in our models, their probability figure is about 0.29.

It would appear that the transmission probability of the circular chevron baffle models can be improved by going to larger outside diameter. For example, the outside diameter could be five feet instead of four feet for a 35" diffusion pump.

The transmission probability of the last baffle having 4 horizontal annular blocking plates and a central circular plate was only 0.26. This baffle was included because of simplicity in manufacture, but the reduced transmission does not justify its use generally.

C. EXPERIMENTAL RESULTS

The results obtained with a series of conductance measurements were normalized to make direct comparison between various baffles possible. The basis of comparison was the ratio of the conductance of a given baffle model to the conductance of an orifice having the same diameter as the characteristic diameter of the model configuration. This ratio is equivalent to the transmission probability as used by Levenson, Milleron and Davis[6].

The values obtained for the conical transition pieces (Fig. 6) are summarized in the following table. The selected characteristic diameter was the exit, or the smaller diameter of the cones.

TABLE 1

TRANSMISSION PROBABILITY OF CONICAL REDUCER SECTIONS

Fig. No.	D/D_o	L/D_o	L/R_o	Transmission Probability*	Monte Carlo*
6a	1.25	1.5	3.0	0.61	.565
6b	1.25	1.0	2.0	0.75	.685
6c	1.25	0.5	1.0	0.90	.82
12d	1.5	0.667	1.3	0.84	.85
6d	1.5	1.0	2.0	0.84	.75
6e	1.5	0.5	1.0	0.92	.90
12a	2	0.667	1.3	0.91	.89

* Referenced to outlet dimension of 3".

It may be concluded that a short transition piece giving a transmission probability of 0.92 does not represent a serious conductance limitation.

The results obtained with the elbow-shaped ducts are shown in the next table.

TABLE 2

TRANSMISSION PROBABILITY OF ELBOW-SHAPED DUCTS

Fig. No.	Description	Transmission Probability	Levenson[6]
8a	Short, equal legs, not tight	0.26	
8b	With eye-shaped baffle	0.23	
13d	Same, repeat	0.265	
8c	Long, equal legs, tight	0.21	0.27
8d	Unequal legs	0.18	
8e	Same, reversed	0.18	
13e	2-piece baffle	0.28	

It may be noted here that the value in line 4 of Table 2 is lower than the theoretical value of 0.27 which was confirmed by Levenson et al experimentally. This rather large discrepancy may be due to the interaction between five elbow models placed inside a small chamber, because their entrances converge at the center of the chamber. Some of the models in this series were checked again with only two elbow models in the chamber and showed a higher transmission (line 3 in above Table 2).

The results obtained with the chevron models agree closely with those measured by Levenson and Milleron, as shown in the following table.

TABLE 3

TRANSMISSION PROBABILITY OF CHEVRON BAFFLE MODELS

Fig. No.	Description	Transmission Probability	Levenson[6]
10a	Outer walls only	0.48	
10b	Single disk	0.23	
10c	3" high model	0.26	calculated values 0.25 - 0.27 measured values 0.23
10d	2" high model	0.25	
10e	1.5" high model	0.22	

The transmission probabilities of the last baffle series are shown in the final table below:

TABLE 4

TRANSMISSION PROBABILITY OF CIRCULAR CHEVRON BAFFLE MODELS

Fig. No.	D/D_o	L/D_o	Transmission Probability
13a	1.29	1.33	0.35
13b	1.29	1.33	0.33
13c	1.29	1.33	0.26
13d	(elbow)		0.265
13e	(elbow)		0.28

Studies in reference (6) indicate that transmission factors higher than 0.4 are hardly possible with a baffle of reasonable size, provided that the baffle is "optically tight." Among the highest values obtained were baffles with a single blocking disk. The choice of our final baffle design was made according to the following reasoning. If the single blocking plate (Fig. 10b) is replaced by a chevron arrangement (Fig. 2b), a small increase in conductance could be expected. A baffle made entirely of chevron plates does not give a high conductance (Fig. 10e) unless the diameter of the baffle is much larger than the diameter of the pump. If the diameter is increased, then the shape of the duct might as well be utilized by providing a cooled outer shell near the external wall (Fig. 2b). Next, the attempt is made to obtain further improvement by separating the chevron assembly and locating the conical sections along the diagonals of the baffle (Fig. 13a and 13b).

Comparing the transmission factors for baffles in Fig. 13 to the best baffles of conventional geometry, it may be noted that about the same conductance is obtained in a somewhat smaller baffle.

III. BAFFLE AND PUMP PERFORMANCE

A baffle having an exit diameter of 35" was built according to the geometry shown in Fig. 13a and tested with a standard 35" pump (HS32-50,000). The external dimensions of the baffle have $R/R_o = 1.54$ and $L/R_o = 3.2$; the internal dimensions (the refrigerated section) have $R/R_o = 1.48$ and $L/R_o = 2.3$. The construction of this baffle is shown in Fig. 15.

The pumping speed with the baffle was measured with a test dome having the same diameter as the entrance of the baffle. A long pipe with a series of small holes was placed in the middle of the dome. The holes were pointed upward to eliminate beaming, and an ionization gauge was installed near the flange of the dome. The pumping speed was then measured in the conventional manner, giving values between 23,000 and 24,000 l/s as shown in Fig. 16. An NRC Model HS32-50,000 production pump, taken from stock, was used for these measurements.

The pumping speed of the pump itself was measured, using conventional equipment for speed measurements, i.e., using a test dome of the same diameter as the pump and about 1.5 times as high, and the pressure measured near the inlet flange of the pump. The air was introduced through a pipe with a series of openings directed upward to avoid excessive beaming. The pressure was measured with an NRC Model 507 ionization gauge, using 5.7 ma emission current and operated by the NRC Model 710 gauge control. The flat section of the pumping speed curve, in the molecular flow region, was between 48,000 and 49,000 l/s at a power level of 19 kw (Fig. 16). It is seen that approximately 50% of the pump speed has been retained above the baffle.

The pumping speed of the 35" pump has also been measured for hydrogen and helium. The conventional constant pressure speed measurement method was employed with the usual test dome (AVS Tentative Standard).

The gas was introduced into the flow meter (oil manometer) at atmospheric pressure and the pressure measured with an ionization gauge. The gauge was operated in the usual fashion (NRC 507 at 5.7 ma emission) and the values were corrected for the differences in sensitivities to various gases.

The relative sensitivities of some of the ionization gauges have been compared recently in our laboratory, giving the results shown in the following table.

TABLE 5

GAS CORRECTION FACTORS FOR GAUGES

Gauges	553	507	Alphatron(R)	VG-1A	GIC-010
Helium	0.2	0.16	0.13	0.14	0.25
Hydrogen	0.5	0.5	0.25	0.46	0.5
Air	1	1	1	1	1
Nitrogen	1.02	1.0	0.96	1.1	1.2
Argon	1.51	1.31	1.19	1.62	1.8

Accordingly, the values obtained with the 507 ionization gauge were multiplied by 2 in the case of hydrogen, and by 6.2 for helium.

The results of the speed measurements are shown in Fig. 17. The speed for hydrogen is approximately 68,000 l/s and for helium 58,000 l/s. Previously obtained figure for air was about 49,000 l/s. The relative speed values are fairly typical for large diffusion pumps such as NRC 35" pump (HS32-50,000).

IV. COMPARATIVE BACKSTREAMING MEASUREMENTS

A. GENERAL

Usual backstreaming measurements directly above an unbaffled diffusion pump yield values in the order of 5×10^{-4} to 5×10^{-3} mg/cm^2-min when used with a cold cap around the top nozzle*. Without this cold cap the rate can be one or two orders of magnitude higher. It is interesting to compare the above backstreaming values to the rate of evaporation of the pumping fluid at room temperature. For DC-704 silicone oil the maximum theoretical rate of evaporation is approximately 5×10^{-5} mg/cm^2-min, assuming a vapor pressure near 1×10^{-8} torr. Values of that order have been confirmed by experimental measurements for similar oils[10]. The comparison between the rate of evaporation at room temperature from an area equal to the inlet area of the pump and the actual backstreaming rate can be used as a figure of merit for a pump design. This, of course, will vary with different pumping fluids because of differences in vapor pressures.

One of the aspects in this study was to compare the backstreaming rates of two fluids above a liquid nitrogen cooled baffle. The two fluids used were DC-705 (Dow Corning Corporation) and Convalex-10 (Consolidated Vacuum Corporation). It is apparent that if the baffle reduces the backstreaming by a factor of 10^3, the rate of arrival of oil molecules at the collecting surface above the baffle will be lower than the possible rate of evaporation. For this reason, the collector surface during operation must be cooled to prevent errors due to evaporation.

Before proceeding with the baffle tests, measurements of direct backstreaming rate of the 6" pump fitted with a cold cap were made. No significant difference was observed between the two pumping fluids used. The steady state rate measured with Convalex-10 was 0.0285 cc/hr and with DC-705 0.0298 cc/hr.

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* Licensed exclusively to NRC Equipment Corporation by Edwards High Vacuum, Limited. U.S. Patent No. 2,919,061.

The method of measurement was in accordance with tentative AVS Standards. The results are shown in Fig. 18. The test dome was wetted with the pumping fluid before starting the measurements. The drainage of this fluid produces the high initial rate of collection compared to the final steady state value[4]. The shift of oil level seen in Fig. 18 at 25 and 47 hours is due to emptying of the collecting graduated tube. The measurements with Convalex-10 were carried for a longer period because of the higher viscosity of this fluid which requires a longer time to reach steady state conditions.

B. MEASUREMENT TECHNIQUE

The experimental apparatus used for backstreaming measurements above the liquid nitrogen baffle is shown in Fig. 19.

To avoid the necessity for automatic liquid nitrogen level controlling systems, and to reduce liquid nitrogen losses, a single large liquid nitrogen reservoir is used for feeding both the baffle and the collector plate. The reservoir is large enough to keep the baffle and the collector plate at liquid nitrogen temperatures for at least 15 hours so that only 8:00 A.M. and 5:00 P.M. charging is necessary. The rest of the baffle is cooled by conduction through copper ribs.

The baffle is similar to the standard NRC circular chevron baffle designs, but it is modified to approximate the geometry of the full size 35" pump baffle (Fig. 15). The backstreaming collector plate is made of two halves to permit removal for weighing. The plate was made of aluminum for high thermal conductivity. It was clamped to the bottom of the liquid nitrogen reservoir and cooled by conduction. The collector plate is wrapped with aluminum foil which is weighed before and after the test. Its weight was about 6 grams, which permitted weighing with an accuracy of about 0.1 milligrams. This corresponds to a weight of about two monolayers of oil molecules deposited on the surface of the liquid nitrogen collector. Usually, after two weeks of continuous operation, the accumulation on the collecting foils was sufficient to permit an accurate measurement. To check the accuracy of such measurements, a laboratory analytical balance was used to measure the weight of the foil (6" x 6") before and after application of the oil layers. The thicknesses of oil films ranged from 1 to 25 molecular layers. The accuracy of these measurements appeared to be about ± 1 monolayer, which corresponds roughly to a tenth of a milligram. If larger foil areas are used for measurements with the 35" pump baffle, the accuracy can be improved sufficiently to allow discrimination between one and two monolayer equivalents (assuming uniform distribution).

Auxiliary experiments were made to determine whether any serious errors were introduced during starting and stopping the diffusion pump, and also due to the condensation of water vapor on the collecting surface. The condensation of water vapor on the collector at liquid nitrogen temperature was expected to be one source of error. However, the large difference of vapor pressure between water and diffusion pump oil should make it possible to "degas" the oil deposit by mild heating. Errors involving condensable vapors other than pumping fluid should give more conservative backstreaming values and they will not be very disturbing for comparative measurements with two different pumping fluids.

During actual backstreaming measurements, at the end of a collecting period, the collecting surface can be allowed to warm up before opening the chamber and weighing, or it can be removed while still cold. In the latter case, moisture from atmosphere condenses on the cold collector surface.

Some experiments were performed to check the possibility of evaporating the water without evaporating the oil. An oil droplet (DC-705) was dissolved in acetone and then the solution was evaporated in a vacuum chamber for about 10 minutes duration. Typical values obtained are listed below.

TABLE 6

OIL WEIGHING EXPERIMENT

Weight of drop before dissolving	0.0477 gram
After evaporating acetone	0.0478 "
After one hour (in the balance)	0.0478 "
After five hours	0.0475 "

When the system was air released with the trap cold, a layer of frost was deposited on the foil used to collect the backstreaming oil. When the foil was removed and allowed to warm to room temperature, water droplets could be seen on top of the oil deposit. These droplets were removed after exposing the foil to vacuum for 10 minutes in a small chamber pumped by a mechanical pump. The foil was weighed and its weight was checked the next day. There was no significant difference. Next, the foil was rinsed with acetone and its original weight checked after removing the oil deposit. Typical results are shown in Table 7.

Additional experiments were conducted to make sure that the collected backstreaming oil can be separated from condensed water vapor during final measurements. For this purpose, aluminum foils having a measured amount of oil deposit were placed in a freezer. The accumulated water vapor was later evaporated by a brief exposure to vacuum. The results indicate that the amount of original oil deposit remained unchanged.

There seems to be little question that measurement errors will not be serious whether the backstreaming collecting surfaces are removed from the system while still cold, or allowed to warm up before exposure to atmosphere. This is at least true in the case of the heavy hydrocarbon molecules associated with "oil" backstreaming. The lighter hydrocarbons, which may be formed due to pumping fluid breakdown, are essentially non-condensable and can be detected by partial pressure measurements.

TABLE 7

TYPICAL BACKSTREAMING MEASUREMENT DATA

Operating time	250 hr
Initial weight of foil	6.3030 g
Weight after 250 hr exposure to operating pump	6.3102 g
Weight after short vacuum exposure to detect any adsorbed water	6.3102 g
Weight after acetone rinse and exposure to vacuum to check original weight	6.3036 g
Weight after second acetone rinse and exposure to vacuum at 60°C	6.3029 g
Amount of collected oil	0.0072 g
Area of collector surface	478 cm^2
Backstreaming rate	1×10^{-6} mg/cm^2-min.

C. EXPERIMENTAL RESULTS

The backstreaming collecting system performed according to expectations. The liquid nitrogen reservoir was sufficiently large to keep the baffle cold for a period of about 20 hours. It was only necessary to fill it up once in the morning and once in the evening. With both fluids the pressure indicated by the ionization gauge was in the range of 1 to 5 x 10^{-9} torr, except during the first two days of operation. A 6" diffusion pump (HS6-1500) was used and the seals were Viton O-rings. The entire test chamber was insulated by glass wool. As a result, the external wall and the O-rings were near 0°C when the reservoir was filled with liquid nitrogen. This also reduced the possibility of creep along the chamber wall.

The results of several tests made with this system are shown in Table 8. The reason for the higher backstreaming rate with DC-705 is not clear and this problem requires further study. The ultimate pressures obtained during these tests were actually somewhat lower with DC-705, and the backstreaming rates of the unbaffled pump with the two fluids were almost identical.

Taking the averages of two measurements, the backstreaming rate with DC-705 is about 8 times higher. If the major mechanism of backstreaming were due to oil-to-oil collisions, such a large difference would not be expected since the primary backstreaming with the two fluids was almost identical. The remaining possibilities include differences between sticking coefficients, or differences in creep rates along the uncooled wall and subsequent evaporation onto the collecting surface.

TABLE 8

COMPARATIVE BACKSTREAMING RESULTS

Fluid	Period, Hr.	Rate, mg/cm^2-min.
Convalex-10	435	3.8×10^{-7}
	250	1×10^{-6}
DC-705	380	6.5×10^{-6}
	170	5.3×10^{-6}

It is interesting to note that, after a total operating period of about 40 days accumulated with this system, there were no bulk oil films noticeable above the trap. The only clearly wet area (aside from the baffle surfaces) was at the bottom of the cylindrical chamber, approximately 2" from the pump flange (line A-A in Fig. 19). This 2" high cylindrical area between the liquid nitrogen cooled baffle and the pump is created by the shadow of the baffle on the chamber walls. This area can be reached by the primary backstreaming flow. The line of separation between the area covered by the heavy liquid film (which had draining streamers) and the apparently dry area was very sharp, and did not advance after the first test. Apparently, the rest of the uncooled walls become covered with a few monolayers of pumping fluid molecules, after which an equilibrium is established between the rate of arriving and evaporating molecules. In other words, the surfaces which are at room temperature and are shielded from exposure to primary backstreaming do not accumulate continuously growing oil deposits.

D. EXPERIMENTS WITH WATER-COOLED BAFFLES

Several additional experiments were performed with the 6" system. The first was operated as previously, except a water cooled baffle of standard design (NRC-0314-6) was included between the pump and the liquid nitrogen trap (Fig. 20). In addition to the usual oil collecting foil, a collecting band was placed around the cylindrical surface of the liquid nitrogen reservoir (near section BB, Fig. 20). The test was conducted for a period of 240 hours. The resulting backstreaming rate was

2.8×10^{-7} mg/cm^2-min at the usual collector, and 7.3×10^{-8} mg/cm^2-min at the cylindrical band. The oil used in this test was DC-705. The water-cooled baffle surfaces were deliberately wetted with oil to start the test with a saturated baffle.

The second test was made to check the backstreaming rate while eliminating the possibility of oil creep and bypass around the periphery of the liquid nitrogen trap. For this purpose a large sheet of aluminum foil was wrapped around the liquid nitrogen trap and the cylindrical reservoir (between sections AA and BB, Fig. 20). Providing sufficient overlap of the foil and using tight wire clamping on both ends, any passage to the collector was eliminated except through the trap itself. An additional band collector was used around the cylinder, as in the first test. The period of operation was 337 hours. Again, DC-705 was the pump fluid and the water cooled baffle was included as before.

The collected amounts were 1.2×10^{-7} mg/cm^2-min for the usual disk collector, and 1.1×10^{-7} mg/cm^2-min for the band.

Next, the first test was repeated, using the creep barrier arrangement as described above. The duration was 240 hours, and the test was performed exactly as before, except in this case the liquid nitrogen baffle was allowed to warm up (by blowing room temperature air into the reservoir) before it was opened to atmosphere. The warming up period was about three hours. The values obtained were 8.7×10^{-8} mg/cm^2-min at the disk above the liquid nitrogen baffle, and 9.4×10^{-8} mg/cm^2-min at the band around the upper reservoir. These results indicate that the water-cooled baffle reduced the amount of backstreaming by about 50 times, compared to the measurements obtained without the baffle.

The second test indicates that the absence of a creep barrier in previous measurements did not introduce errors much higher than a factor of two.

One final test with this system was performed to eliminate the possibility of errors associated with starting and stopping the diffusion pump and the initial evacuation by the mechanical pump. The test was conducted according to the usual procedure, except the diffusion pump was operated only long enough to reach 10^{-5} torr pressure range and the baffle was not cooled with liquid nitrogen. In this case there was no measurable accumulation on the collector foils.

V. BACKSTREAMING MEASUREMENTS

A. EXPERIMENTAL SETUP

The 35" pump (HS32-50,000) and the baffle described in Section III (Fig. 15) were used for backstreaming measurements in the cross-sectional plane a few inches above the baffle

entrance. The method of measurement was similar to the one described in Section IV. During most of the tests, the baffle was continuously cooled with liquid nitrogen.

As shown in Fig. 15, the external cylindrical shell and the flat disk in the center of the baffle were cooled by direct contact with a pipe carrying liquid nitrogen. The remaining members were cooled by conduction through six pairs of diagonally arranged copper gusset plates. The small vertical reservoir in the center was used for automatic liquid nitrogen level control arrangement. The additional space at the top and bottom of the refrigerated section was provided for the liquid nitrogen supply pipe and to reduce the amount of oil condensed on the lowest conical section.

Instead of relying on a bank of smaller liquid nitrogen containers to operate the baffle overnight, a 600 liter tank was installed and connected to the baffle by insulated lines. This tank capacity was sufficient for two days of operation. In the original installation, liquid nitrogen consumption was near 20 liters per hour. To reduce the liquid nitrogen consumption, the external shroud of the baffle was insulated by layers of NRC-2 insulation (Fig. 25). The presence of insulation in the vacuum did not interfere with reducing the pressure to 1×10^{-9} torr.

The external walls of the baffle and the test dome above it were wrapped in glass wool insulation to reduce the amount of heat transfer to the liquid nitrogen shroud. As a result, the external walls were near 10°C when liquid nitrogen was used to cool the baffle.

After improvement of insulation, the liquid nitrogen consumption in the baffle itself was reduced to about 10 to 11 liters per hour. In addition, about 4 to 5 liters per hour are lost in the 30 ft long supply pipe and the storage tank.

A photograph of the setup is shown in Fig. 21.

The oil collecting surface consisted of three strips of aluminum foil 4" wide, held in a triangular position above the cold trap. The total aluminum foil surface directly exposed to the backstreaming oil measured approximately 2600 cm^2. The aluminum foils, as shown in Fig. 22, are wrapped around three copper plates (4" x 15" x .125) which have 3" of their length clamped to the last conical ring of the baffle, and 12" exposed above it. Clips were used to assure a good contact between the copper plates and the aluminum foils.

The baffle was sealed to the diffusion pump by a butyl rubber O-ring. The seal between the test dome and the baffle consisted of two silicon rubber O-rings with the space between them evacuated by the mechanical pump.

Temperature measurements on the oil collecting surfaces were made by attaching copper-constantan thermocouples on the aluminum foils. One thermocouple was at the middle point of one of the strips connecting two copper plates. The other thermocouple was directly attached to one of the conical rings of the baffle (Fig. 22). The ends of these collector foils were wrapped around copper plates which were, in turn, clamped to the upper conical baffle section (Fig. 22). Temperatures obtained were derived from readings taken at 10-minute intervals, as shown in Fig. 23.

The temperatures in various locations were found to be close to -320°F. About two hours were necessary for the warmest parts of the baffle to approach liquid nitrogen temperature during initial cooling. In the middle of the aluminum foil strips used to measure backstreaming rates, the temperature was near -220°F, and it also reached a steady state about two hours after the start of cooling. At their ends, the foils were near liquid nitrogen temperature.

Before the start of the tests, the baffle and the dome were subjected to a mild bakeout (100 - 150°C, with external heating cables) for initial cleaning. After that no cleaning was done between successive runs, except that the three copper plates which come in contact with the foils were wiped with acetone. Usually, the mechanical pump and the diffusion pump heaters were started almost simultaneously and the liquid nitrogen cooling was begun as soon as the pressure was reduced to the high vacuum range. In some cases the system was air released after allowing the baffle to warm up to near room temperature; in others the chamber was air released while the baffle was still cold enough to condense water vapor from the atmosphere.

At the end of a run, when the diffusion pump oil was cold, the system was air released through a small valve placed at the bottom of the cold trap to eliminate direct air blow on the aluminum foils.

Moisture from the air, which condensed on the cold aluminum foils while in contact with the cold trap, seemed to disappear a few minutes later, when the foils were exposed to room temperature.

Usually, the collected oil film was barely visible to the naked eye. The three strips of aluminum foil, covered with the oil film, were weighed twice: once soon after they were removed from the cold trap, and once after they were placed in a vacuum chamber for 10 minutes to evaporate any gas or moisture which may have been dissolved in the oil film. After these weighings were made, the three aluminum foil strips were thoroughly rinsed with acetone, placed overnight in a vacuum oven (temperature set at 60°C), and then reweighed to check their original weight.

Before proceeding with the measurements with the liquid nitrogen baffle, the primary backstreaming was checked to provide a reference value. The backstreaming rate was measured with a collecting cone placed at the inlet plane of the pump[4]. The measured rate was 0.275 cc/hr with a cold cap (the cold cap is a standard part of this pump), which corresponds to about 7×10^{-3} mg/cm^2-min. In this test the pumping fluid used was DC-705.

B. EXPERIMENTAL RESULTS

The summary of measurement results obtained with the 35" pump system is shown in the table below. The pumping fluid used during these measurements was DC-705. The pressure indicated by the ionization gauge during most of the operating time was near 2×10^{-9} torr.

The first two tests were made without any cooling, and no accumulation could be measured by weighing the foils. The weighing method is not sensitive enough to detect the presence of one monolayer, after which apparently no additional accumulation is produced.

The first run was made using strips of aluminum foils (2" x 18") placed across the uppermost conical sections of the baffle. After 100 hours of operation, the weight of the foils had not changed at all and the upper surfaces of the baffle and the test dome walls felt dry to touch and appeared dry by visual inspection.

Tests 3 through 9 were made with continuous liquid nitrogen cooling, except in test no. 4 in which the liquid nitrogen was used only during two-thirds of the total operating time, that is the last 220 hours of the run the cold trap was cooled by liquid nitrogen.

In test no. 3 minor malfunctions of the liquid nitrogen storage equipment caused partial warming of the trap on two or three occasions.

The fifth test was terminated after 63 hours, due to a general power failure, which occurred during the night. The system was arranged so that the foreline valve closed automatically in the event of power failure.

TABLE 9

SUMMARY OF BACKSTREAMING MEASUREMENTS

Test No.	Backstreaming Rate $mg/cm^2/-min.$	Time Hours	Remarks
1	not measurable	100	No liquid nitrogen
1a	--	2 (90)	Temperature measurements only
2	not measurable	157	No liquid nitrogen
3	3.9×10^{-7}	166	Liquid nitrogen used. Liquid nitrogen system malfunctioned
4	4.2×10^{-7}	220 (335)	Liquid nitrogen used for 220 hr *
5	7.3×10^{-7}	63	Liquid nitrogen used. Test terminated due to power failure
6	6.6×10^{-7}	71	Liquid nitrogen used
7	1.9×10^{-7}	218	Liquid nitrogen used
8	7×10^{-8}	524	Liquid nitrogen used. Cold cap and cylindrical guard wrapped in aluminum foil
9	3×10^{-6}	3 (5)	Liquid nitrogen used for 3 hr. Start up and shut down test.

* Backstreaming rate computed based on the amount collected during the 220 hours of liquid nitrogen cooling.

After examination of values shown in the table, it was noticed that shorter tests tend to have higher backstreaming rates. To make sure that starting and stopping procedure was not contributing the major portion of collected pumping fluid, the final short test was performed. In this test the liquid nitrogen level controlling arrangement indicated that the reservoir in the center of the baffle was filled only for a period of a half hour. However, it was estimated that the baffle remained cold for a period of two to three hours.

If the total amount collected in test no. 9 is subtracted from the amount collected in test no. 8, the backstreaming rate for the latter will be about 5×10^{-8} mg/cm^2-min. This is hardly a significant correction for the 500 hour test, but it will be greater for the shorter runs.

To give a better understanding of major sources of backstreaming in this system, the pattern of oil deposits in the entire baffle was carefully examined. After an accumulated operation time of about 1500 hours with liquid nitrogen, and a total period of about 1700 hours, the lower surfaces of the baffle show a clear line of separation between heavy oil deposits and a very light oil film. The surfaces above the baffle near the upper flange and inside the test dome appear almost dry. A tissue paper rubbed on the surface near the upper flange does not become oily, but acquired a slight grey or black deposit.

The regions of heavy oil deposits are indicated in Fig. 24 by crosshatching. When the geometry of the baffle is examined in regard to these heavy deposits, it becomes apparent that the major source of backstreaming is near the top jet of the pump. All shadow lines appear to converge to an area near the cylindrical water-cooled guard around the cold cap and the annular area between the guard and the cold cap.

It is possible that the higher flux of oil vapor from this annular area provides the major source of backstreaming. In addition, the top jet and the cold cap assembly of the pump were attached to the rest of the jet system by a threaded rod, and there is a possibility of small vapor leaks along the thread.

To eliminate these suspected sources, in test no. 8 (Table 9) the entire cold cap assembly and the cylindrical guard were wrapped with aluminum foil to reduce the primary backstreaming rate. Since the trapping system being used does not utilize a water-cooled baffle (between pump and liquid nitrogen cooled baffle), it is possible that the final backstreaming rate will directly depend on the backstreaming of the pump itself.

The values in the summary table are averages of measurements obtained from three symmetrically located aluminum foil strips (Fig. 22). The uniformity of angular distribution can be seen in the following table showing typical results. (Table 10)

During several tests, in addition to backstreaming rate measurements above the baffle, the oil deposition rates in the upper section of the baffle were measured. These positions are indicated in Fig. 25 by letters A, B, C, D. This was done to obtain a measure of molecular densities in the upper regions of the baffle in order to gain some appreciation of oil-to-oil molecule collisions. In certain regions of the baffle, such

collisions can change the path of molecules and divert them into the vacuum chamber without striking a cold surface.

TABLE 10

BACKSTREAMING MEASUREMENTS
WITH SYMMETRICALLY LOCATED ALUMINUM FOIL STRIPS

	1	2	3
Original weight of foils (g)	16.0714	15.8934	15.8622
Weight after test	16.0756	15.8985	15.8673
Weight after "degassing" by a brief exposure to vacuum	16.0756	15.8981	15.8673
Weight after acetone rinse and degassing at 60°C	16.0701	15.8936	15.8626
Net weight of oil film	0.0042	0.0051	0.0051
Total weight		0.0144 g	
Total surface area		2600 cm^2	
Time of operation at LN_2		220.6 hr	
Backstreaming rate		4.2×10^{-7} mg/cm^2-min	

The results of the oil deposition rates in positions shown in Fig. 25 are presented in the following table.

TABLE 11

MEASUREMENTS OF OIL DEPOSITION RATES
AT VARIOUS POINTS IN THE BAFFLE
(mg/cm^2-min)

	A	B	C	D
Test 1	$.8 \times 10^{-5}$	$.9 \times 10^{-5}$	1.4×10^{-5}	
Test 2		2.5×10^{-4}	4.3×10^{-4}	
		4.7×10^{-4}	2×10^{-4}	
Test 3*	4.2×10^{-4}	4.1×10^{-4}	1.8×10^{-4}	1.1×10^{-4}

* Averages from 3 foils spaced 120° apart.

When these values are compared to the backstreaming rate at the pump entrance (7×10^{-3} mg/cm^2-min), it may be observed that they are attenuated in the approximate ratio of the square of the distance from the top nozzle of the pump.

C. RESIDUAL GAS ANALYSIS

During the planning stages of this project, the partial pressure analysis was considered as the main method for monitoring backstreaming above the baffle. However, after a considerable amount of work, it became apparent that it would be extremely difficult to relate the number of backstreaming oil molecules to the ion currents indicated by the mass spectrometer with a reasonable degree of confidence.

The behavior of the residual gas analyzer (GE ZS-8001) in regard to measuring partial pressures of various hydrocarbons was studied in an auxiliary system using a 6" diffusion pump. The details of this work are reported elsewhere[2]. Fig. 26 shows this system with the mass spectrometer tube and controls. The mass spectrometer control was modified in the following manner for ease of taking better spectra. The scan drive was modified with an extremely slow gear drive which insured that the actual peak height was accurately represented. This also proved helpful in distinguishing peaks of small magnitude from background noise and separating adjacent peaks up to mass 100. The recorder was fitted with an additional pen which was mechanically geared to the range selector of the electrometer and provided a range indication for each mass peak. The output of the electrometer amplifier was connected to a simple logic circuit which drove a bidirectional motor attached to the electrometer range selector. This provided a range changing device which would automatically switch ranges when large peaks are scanned. This system was very convenient in that it could be left unattended during the spectrum scan after initial setup and would record peaks differing in amplitude by 5 orders of magnitude with a single scan. A larger magnet (not shown in Fig. 26) was used to obtain more accurate spectra at higher mass numbers.

Figure 27 shows a typical spectrum taken before (solid lines) and after baking the system at total pressures of 7.5×10^{-8} torr and 1×10^{-9} torr as indicated by the Redhead gauge. It should be pointed out that the mass spectrometer tube itself contributes the major gas load in this case. The total pressure in the glass manifold as shown by the cold cathode gauge is about 5×10^{-11}. When the mass spectrometer is turned on, the pressure rises to about 1×10^{-9} torr. In fact, the spectrum is almost completely due to the tube itself. The origins of most of these peaks are discussed by Davis[11], including 19 (fluorine), 23 (sodium), and 39 (potassium).

For comparison, the cracking pattern of benzene (C_6H_6)[12] is shown in the upper part of the graph. Silicone diffusion pump oils (DC-704, DC-705) are methyl-phenyl siloxanes, and in our experience the phenyl group (C_6H_5)was prominent in the spectrum. Numerous experiments performed in this system clearly demonstrate that the mass peaks which can be most conveniently identified with DC-705 fluid are those associated with the phenyl group, mass numbers 50, 51, 52, 77, and 78. In addition, mass 91 is also prominent.

In Fig. 27 the peaks 43 and 58 indicate the presence of acetone which was used for leak testing. This emphasizes the possibilities of errors, particularly in unbaked systems. On one occasion a small leak in the glass system (near the cold cathode gauge) was discovered by spraying the suspected area with acetone. The leak was small enough to permit 3×10^{-8} torr in the system. The acetone cracking pattern was clearly identifiable in the spectrum. The acetone peaks continued to be among the highest, even after three weeks under vacuum (500 hours), and they were removed only after baking.

It is interesting to note that, if the spectrometer had a detection limit of 10^{-12} amps, the only gases that could be seen in the baked system would be hydrogen, methane, water vapor, carbon monoxide and carbon dioxide -- usually found in any vacuum system. For example, Lichtman[13] recently obtained an almost identical spectrum using an ultrahigh vacuum system pumped by sorption and ion-getter pumps. Also, when the same spectrometer is used in an unbaked system pumped by ion-getter pumps, but using rubber gasket seals, it does show peaks in mass ranges 24-29, 38-46, 58-65, 69-72 and 74-82 [14].

For noncondensible gases the current values in amperes obtained at the output of the electron multiplier can be roughly used as pressure values in torr. The multiplier usually produced 10^6 gain. Occasional difficulties of producing very high background have been corrected with no more treatment than baking and cleaning external contacts. A common overall sensitivity (multiplier output) was 1 to 10 amperes per torr at 1 ma electron emission for nitrogen. To be somewhat more accurate, hydrogen currents can be multiplied by 2 to obtain corresponding pressure values in torr, and helium by about 6. At high mass numbers the sensitivity is somewhat uncertain because the ion accelerating voltage becomes very low. We assumed that at mass numbers near 100 the sensitivity dropped by a factor of 10 [15]. This effect should roughly be cancelled by the increase of relative sensitivity for heavier gases compared to nitrogen (for example, benzene, 4.3; and xylene, 5.8, for the Alphatron(R) gauge).

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(R) Reg. U.S. Pat. Off.

However, Hengevoss[16], in a paper treating on this subject, reports that mass 78 (benzene) produces a sensitivity only one-fifth as high as the sensitivity for argon (cycloidal mass spectrometer, DC-704 in the diffusion pump). For this reason we do not have the necessary confidence to convert the output of the mass spectrometer into partial pressures, and prefer to leave it in current values.

During the tests with the 35" pump, in addition to weighing measurements, the residual gas composition in the chamber above the baffle was checked with a mass spectrometer (Fig. 21, mounted on a platform top right). A typical spectrum is shown in Fig. 28. As mentioned before, it is difficult to correlate the mass peaks shown in this spectrum with actual partial pressures, particularly in the case of condensable vapors. Since the system was not baked, many of the peaks are due to the spectrometer tube itself -- for example, peaks 16 and 19, which were unusually high[11]. The hydrogen peak is not shown because the larger magnet does not permit scanning lower masses. The peaks 50, 51, 52, 77 and 78 are due to the pumping fluid, and their intensity usually decreases by one or two orders of magnitude after several days of operation. The spectrum shown in Fig. 28 was taken after four days of operation with the refrigerated baffle. The sensitivity of the spectrometer at the electron multiplier output is in the order of 10 amperes per torr for nitrogen.

Fig. 29 shows results of two spectrograms obtained three days apart. The reduction of magnitudes of various mass peaks is probably due to cleaning of the mass spectrometer tube itself, because it was not accompanied by a corresponding reduction of total pressure.

The three spectrograms taken during the longest run (524 hours) are shown in Fig. 30. In this case, it appears that there are no great changes in partial pressures of hydrocarbons while the total pressure decreased by a factor of three. The decrease of total pressure is reflected by reduction of nitrogen (peaks 14 and 28) and possibly oxygen (peak 32) and hydrogen (not recorded). Other up and down variations can be explained by changes of overall instrument sensitivity (electron multiplier gain and tuning). The peaks associated with the pumping fluid (39, 50-53, 77, 78, 91, 135-137) show a small increase. However, since the water vapor (peaks 17 and 18) show the same increase, this is probably not a genuine rise of partial pressure, but is due to the uncertainties associated with the mass spectrometer. The variations of small peaks in the 10^{-13} ampere range (Fig. 30b) are not significant because at those values the peak height was not reproducible. There are only a few ions per second available at the input to the electron multiplier (10^{-19} ampere).

VI. CONCLUSION

The careful design of a baffle, with the objective of an optimum speed and backstreaming combination in a reasonable size, leads to a conductance improvement of about 20%, compared to conventional simple geometries. Transmission probability of about 0.35 for a minimum single contact baffle is a good design goal. This can be achieved with practical configurations with the baffle diameter not exceeding about 1.5 times the pump diameter. Using conventional method of pumping speed measurements, such a baffle will retain approximately 50% of the pump speed at the inlet to the baffle.

If it is desirable to avoid a water-cooled baffle between the pump and the LN_2 baffle which would further reduce the pumping speed measured at the inlet to the LN_2 baffle, the primary backstreaming should be reduced to a level which will not impede the pump-trap system operation for periods as long as six months (5000 hours). The pump tested in the laboratory had a backstreaming rate of 0.27 cc/hr at the pump entrance, or 1375 cc in 5000 hours. Some of this liquid will drain back into the pump because of the presence of the conical reducer section. The loss of about 1000 cc from the total fluid charge of 3 gallons does not affect the pump performance.

It can be expected that most of this liquid will collect at the lower portions of the liquid nitrogen trap. The lowest conical member of the trap has about 12" width and a mean diameter of 44". This gives an area of 1600 in^2. The layer of the fluid distributed over this area would be about 1/16" thick. This is probably not an objectionable amount and it can be easily reduced by moving upward the lowest cooled baffle surface by lengthening the conical adaptor section. At a distance of approximately 1/3 diameter from the inlet, the backstreaming rate is reduced by about ten times[4]. In this way the oil film could be reduced to a few thousandths of an inch, so that the temperature gradient across the oil film remains very small.

A single refrigerated baffle placed directly above the pump, which retains approximately 50% of the pumping speed, reduces the primary backstreaming rate by four or five orders of magnitude. To measure backstreaming rates above a baffle, it is necessary to refrigerate the collecting surfaces to prevent re-evaporation. Backstreaming oil molecules arriving into a chamber which is at room temperature do not accumulate more than one or two monolayers because of evaporation (equilibrium conditions reached). In other words, the rate of evaporation from the walls and the rate of adsorption on the liquid nitrogen baffle is higher than the rate of arrival of new oil molecules which have passed through the baffle. If

the baffle represents a substantial amount of surface of the chamber, then the coverage on the walls will be less than a monolayer. The degree of coverage will depend on the adsorption characteristics of the oil and the flux of molecules entering the chamber.

The method of measuring backstreaming rates by accumulation on refrigerated foil collectors appears to give reliable results. The disadvantages are the necessity of removing the foils from vacuum for weighing, the length of the experiment, and the associated cost of liquid nitrogen.

The values of measured backstreaming rates are in the same order of magnitude as those obtained by W. M. Langdon[17], and those predicted from the theoretical analysis by C. Tsonis[18]. It should be noted that the conditions and the geometry in our case were different from those treated in the above references. The latter corresponds to the case where a water-cooled baffle is used below the liquid nitrogen baffle, which produced an additional reduction of backstreaming of about 50 times. It may be noted that the reduction obtained by such a water-cooled baffle does not appear great enough (for a pump which has a cold cap) to justify its general use in view of cost increase and loss of net pumping speed.

Under certain conditions, when the backstreaming rate obtained above a single refrigerated baffle placed directly over the diffusion pump is considered to be too high, it may be more advantageous to use a minimum 2-contact refrigerated baffle, rather than a water-cooled baffle and conventional liquid nitrogen trap. Such an arrangement should produce better trapping efficiency and less pumping speed reduction. For example, the chevron geometry (Fig. 1) can be followed by an additional half-chevron array. This will provide a minimum of two contacts for molecules moving in straight paths. Since the additional array is not optically tight, it will have less impedance than a separate water-cooled baffle or a second liquid nitrogen cooled baffle. Even if the major source of oil transfer through the baffle were due to collisions between oil and oil or oil and gas molecules, the additional array will provide higher trapping efficiency.

Together with the backstreaming measurements, the residual gas composition in the test chamber was checked with the mass spectrometer. Typical results show the highest mass peaks (16, 19, 28, 44) in the 10^{-7} to 10^{-8} ampere range, and the heavier hydrocarbon peaks (50, 51, 52, 77, 78) in the 10^{-11} ampere range. The hydrocarbon peaks did not increase significantly with time in long duration tests. The range of total pressures was between 8×10^{-10} and 4×10^{-9} torr.

The errors and uncertainties associated with tubulated ionization gauges are perhaps even more serious with the mass spectrometer residual gas analyzers. This is particularly true in regard to condensable vapors of high molecular weight, so that it is extremely difficult to correlate the ion currents indicated by the mass spectrometer with the rate of backstreaming through the baffle.

REFERENCES

1. Feakes, F. and Torney, F. L., Jr., Trans. 9th National Vacuum Symposium, 1962, Macmillan Co.
2. Hablanian, M. H. and Vitkus, P. L., Trans. 10th National Vacuum Symposium, 1963, Macmillan Co.
3. Hickman, K. C., Trans. 8th National Vacuum Symposium, 1961, Pergamon Press
4. Hablanian, M. H. and Steinherz, H. A., ibid
5. Auwärter, M., Ergebnisse Der Hochvakuumtechnik, Wissenschaftliche Verlag, Stuttgart, 1957
6. Levenson, L, Milleron, N. and Davis, D., Trans. 7th National Vacuum Symposium, 1960, Pergamon Press
7. Nottingham, W. and Torney, F. L., ibid
8. Pinson, J. and Peck, A, Trans. 9th National Vacuum Symposium, 1962, Macmillan Co.
9. Clausing, R. and Levenson, L., Trans. 8th National Vacuum Symposium, 1961, Pergamon Press
10. Buckley, D. H. and Johnson, R. L., NASA TN D-2081, Dec. 1963
11. Davis, W., Trans. 9th National Vacuum Symposium, 1962, Macmillan Co.
12. Rossini, F., Mass Spectral Data, Amer. Petrol. Inst., Proj. 44
13. Lichtman, D., ASTM 11th Conference on Mass Spectrometry, 1963
14. Jackson, D. M., Report No. 3, Proj. 5621, AFCR Contract No. AF 19(604)-8351
15. Davis, W. (G.E. Research Lab) Private Communication

16. Hengevoss, J. and Huber, W., Vacuum, Vol. 13, 1

17. Langdon, W. M., AEDC-TDR-63-174

18. Tsonis, C., Holkeboer, D. and Jones, AEDC-TDR-63-149.

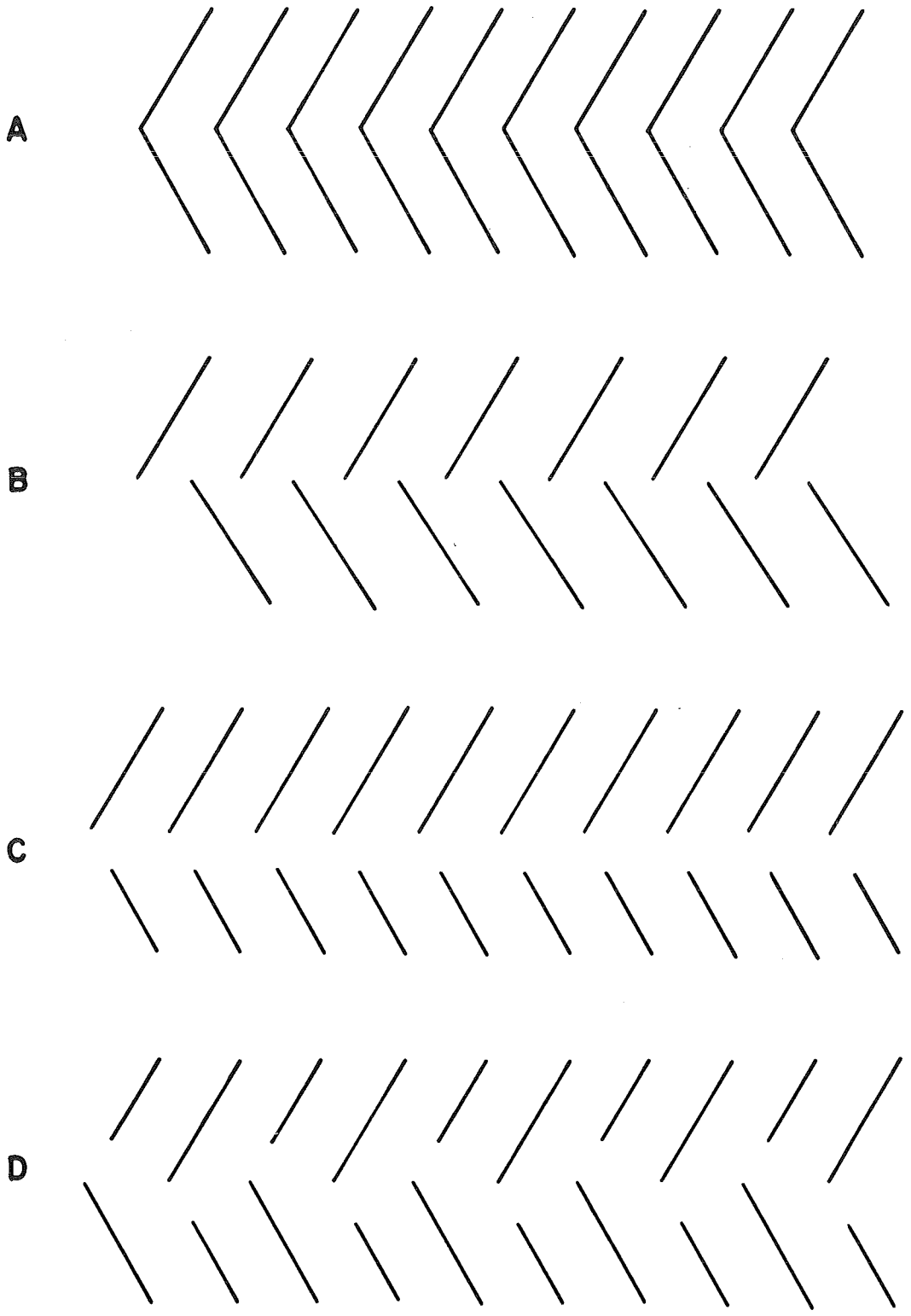
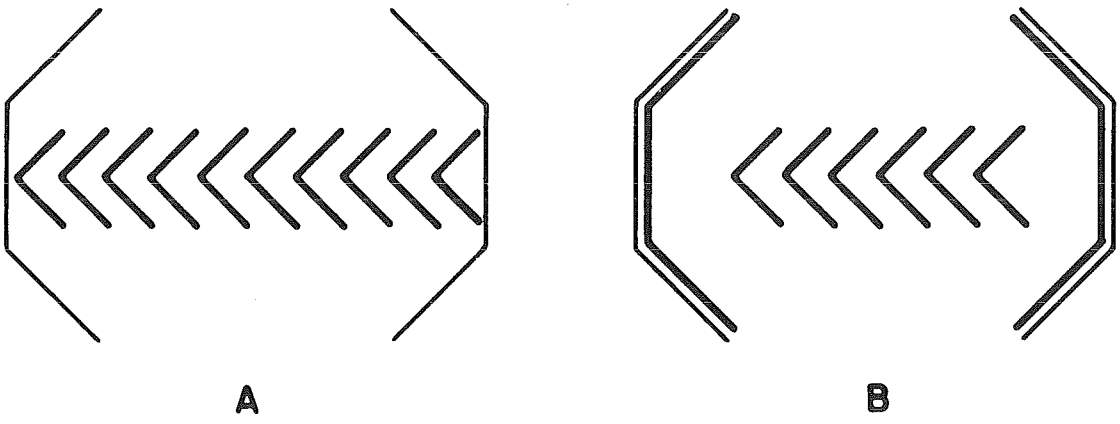


Fig. 1 Common Baffle Chevron Arrays



HEAVY LINES DENOTE
LIQUID-NITROGEN COOLED SURFACES

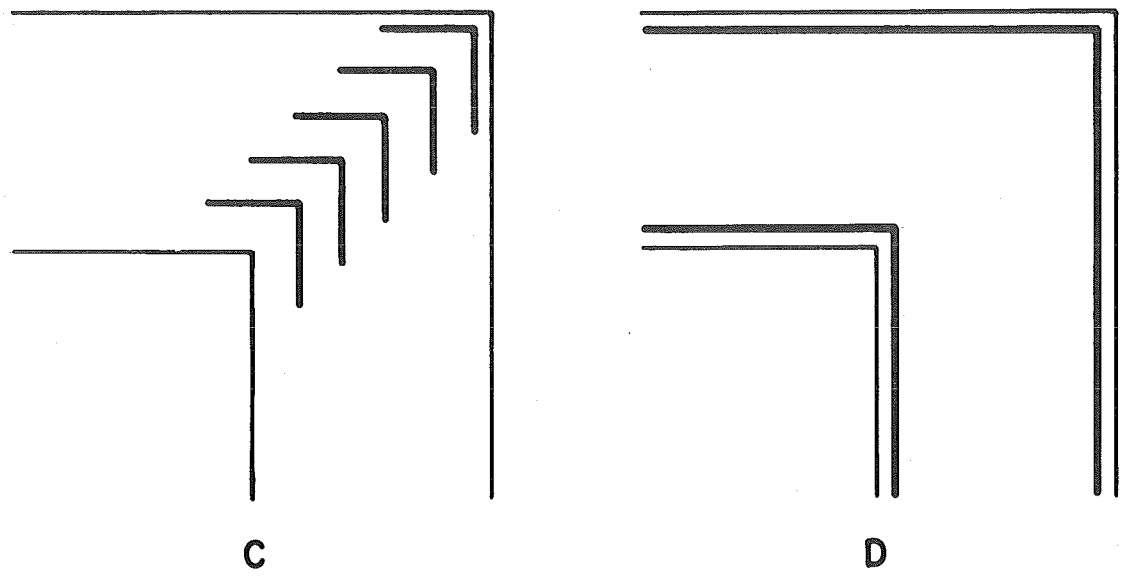


Fig. 2 Straight Through and Right Angle Baffles

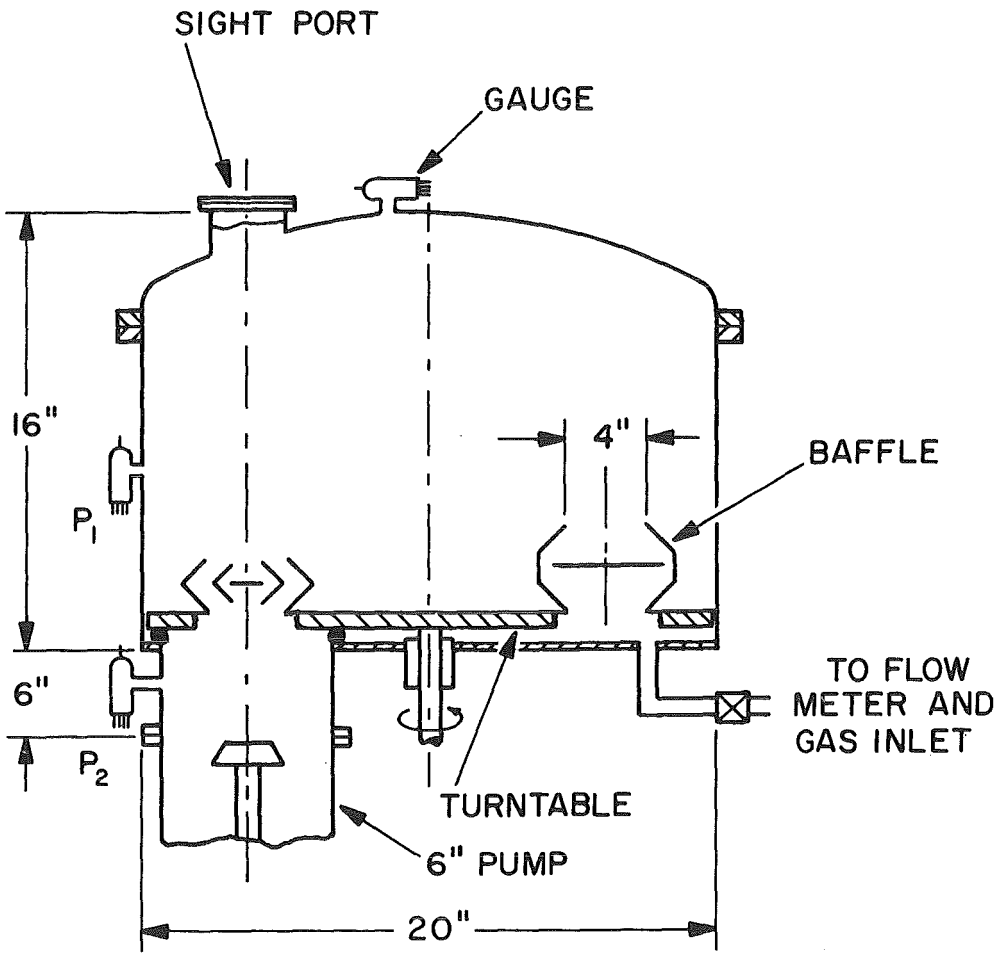


Fig. 3 Schematic of Vacuum Chamber for Model Studies

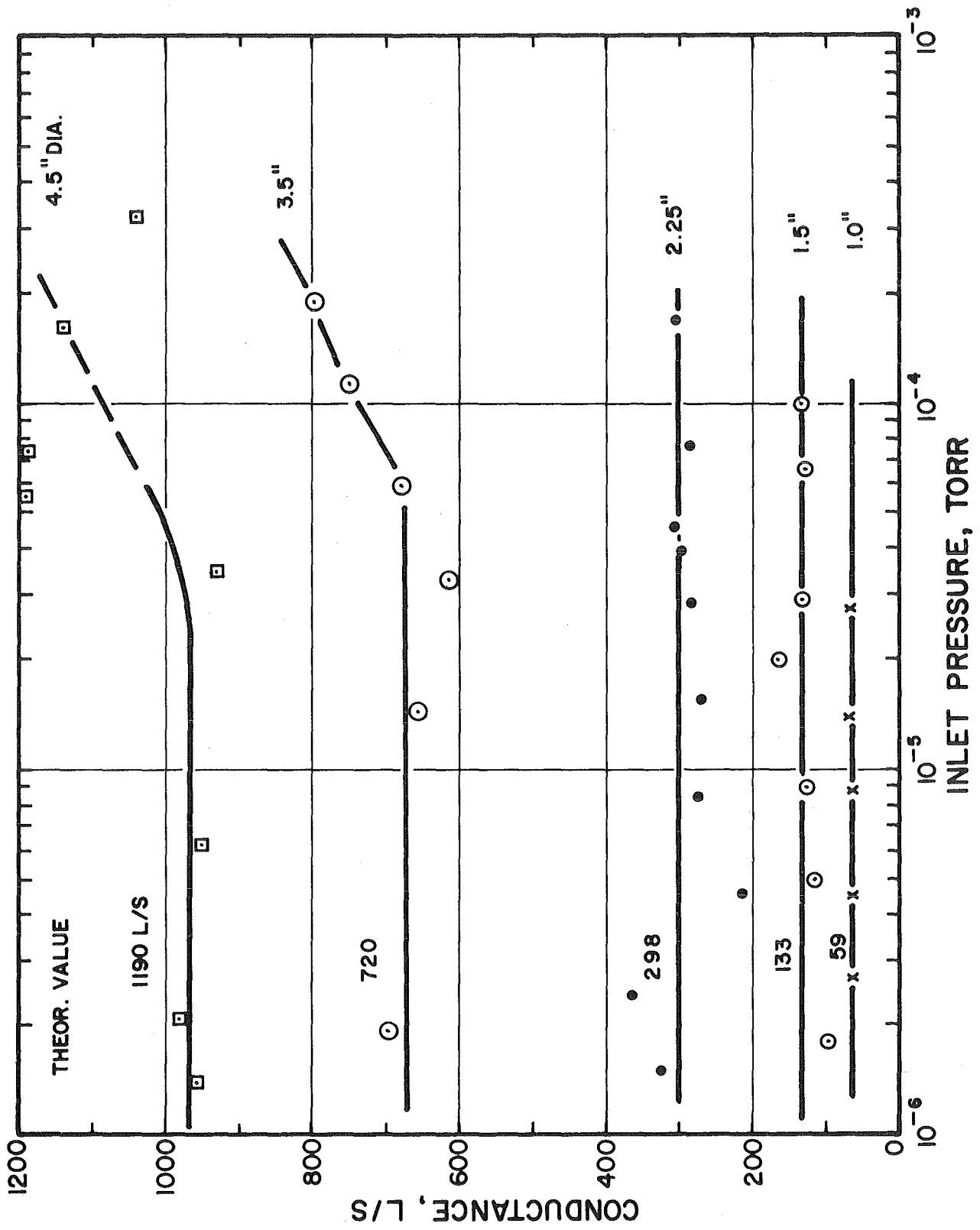


Fig. 4 Orifice Conductance vs Pressure

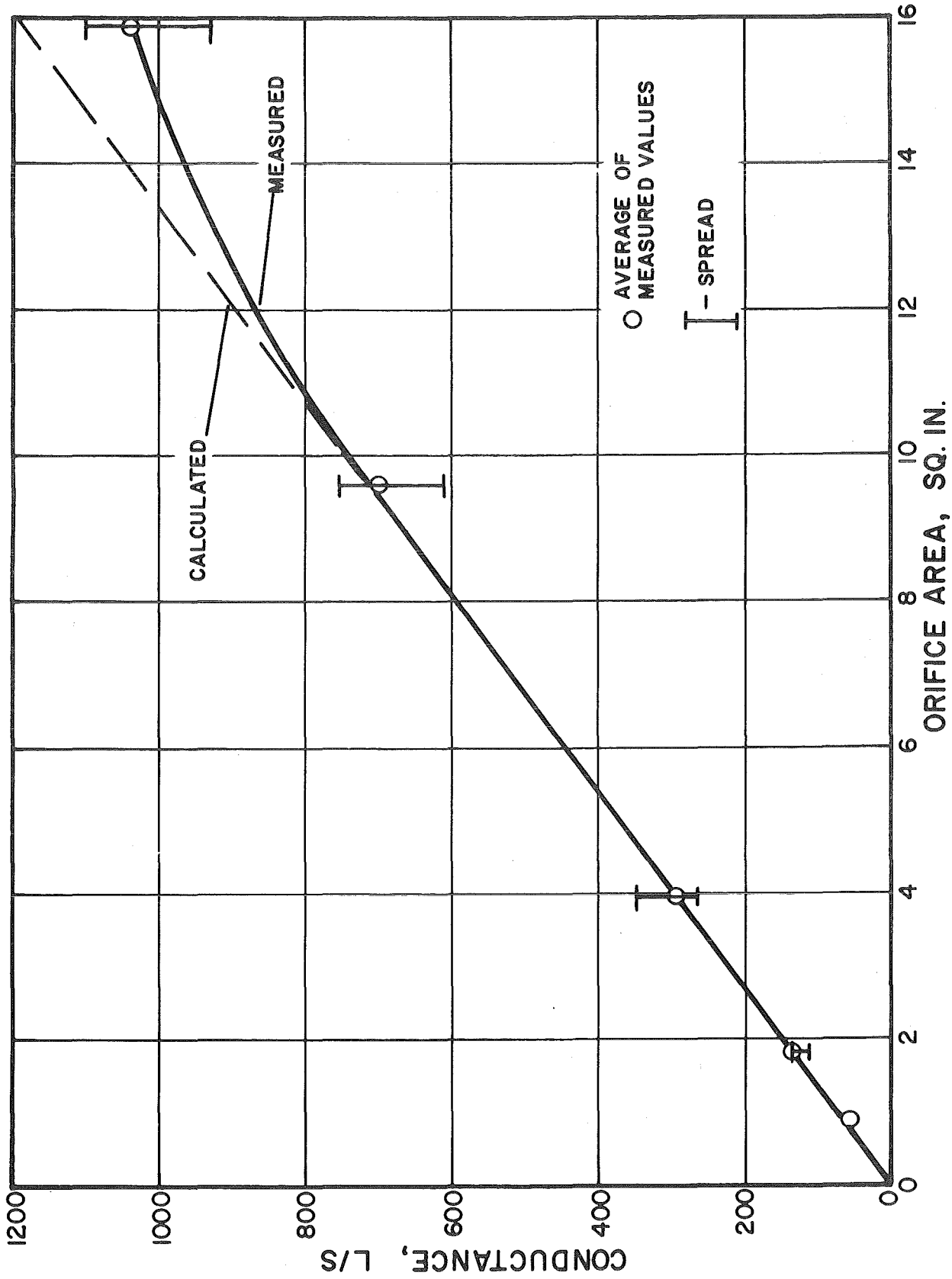


Fig. 5 Circular Orifice Conductance vs Orifice Area

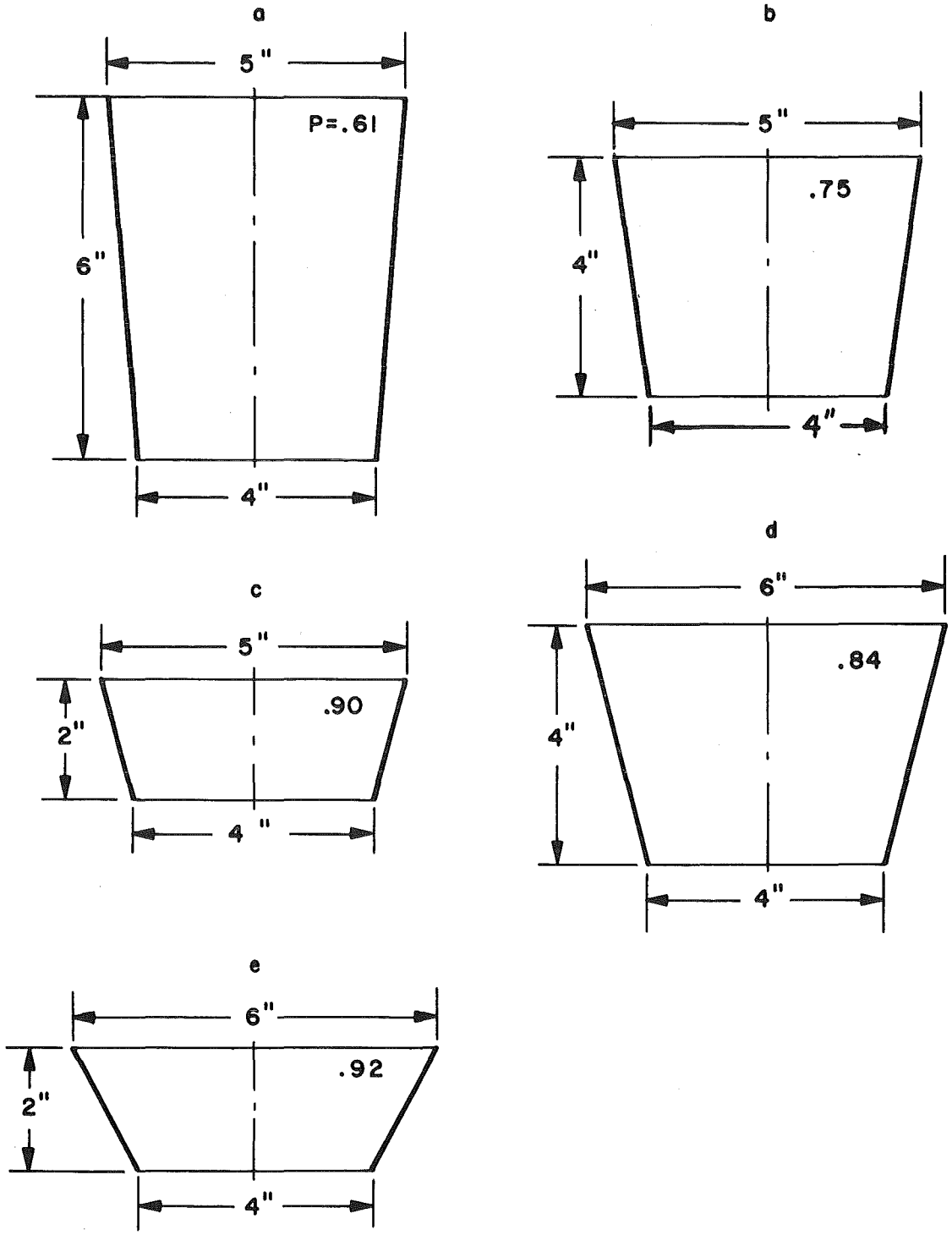


Fig. 6 Conical Duct Sections for Model Tests

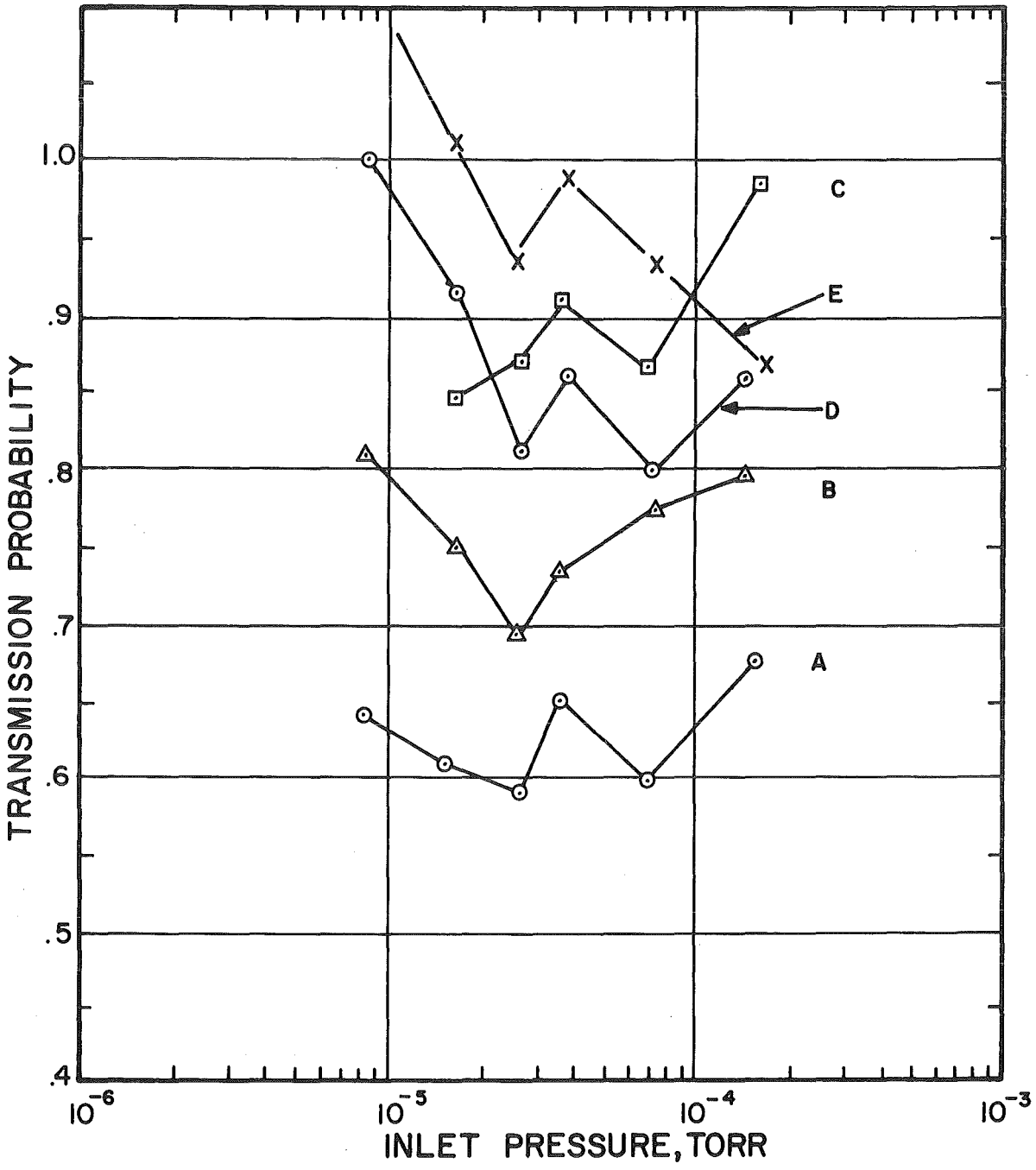


Fig. 7 Transmission Probabilities of Cones Shown in Fig. 6

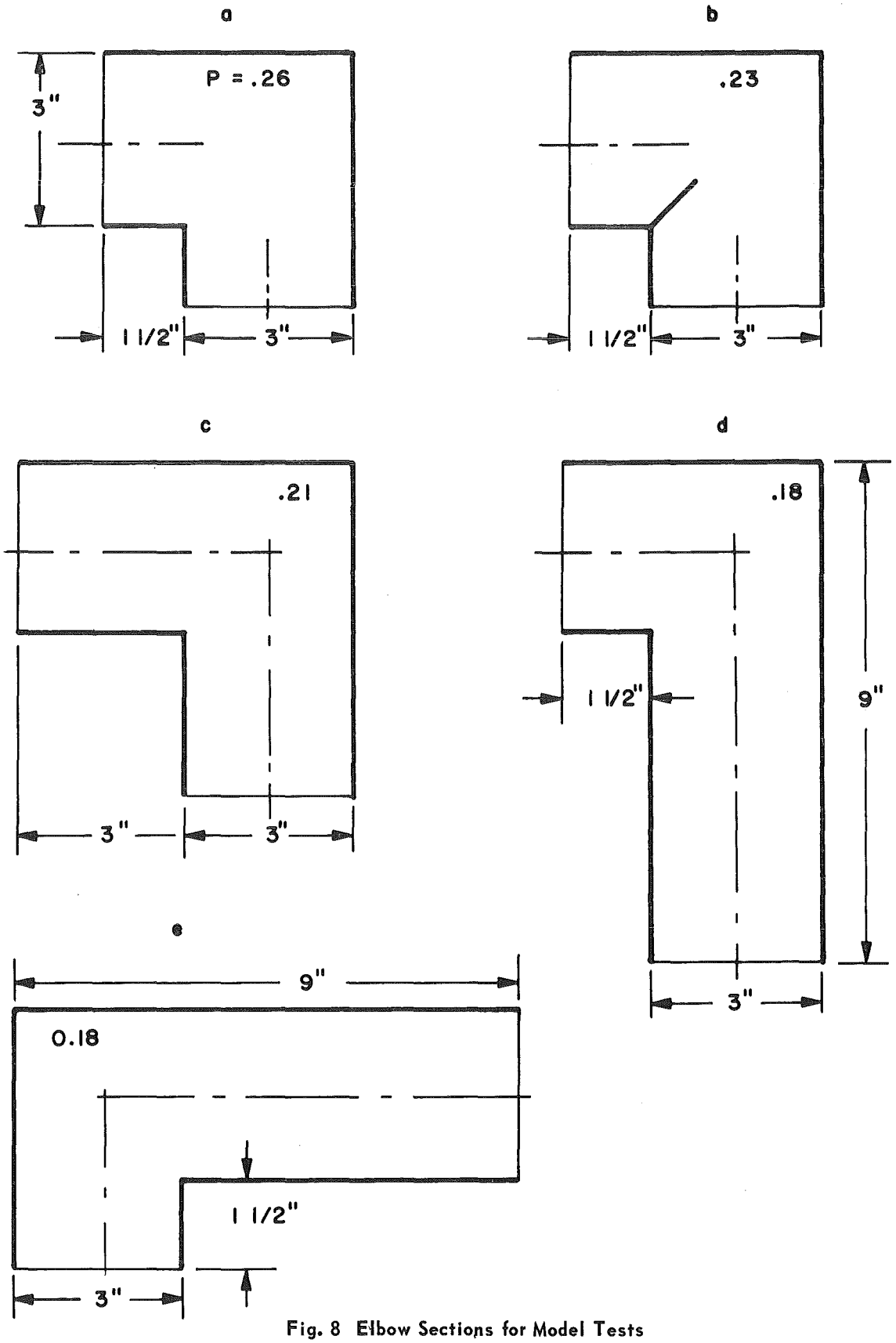


Fig. 8 Elbow Sections for Model Tests

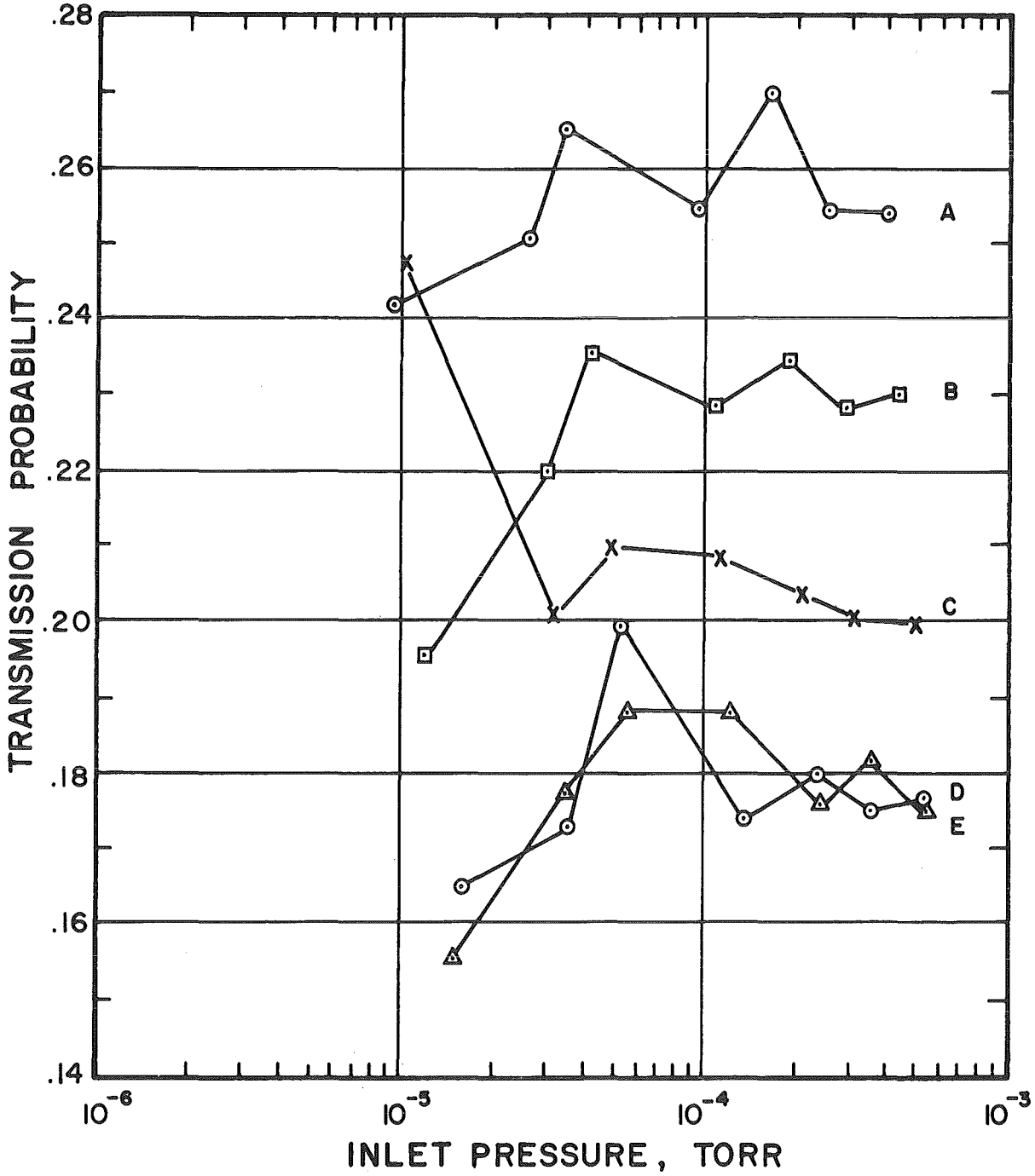


Fig. 9 Transmission Probabilities of Elbows Shown in Fig. 8

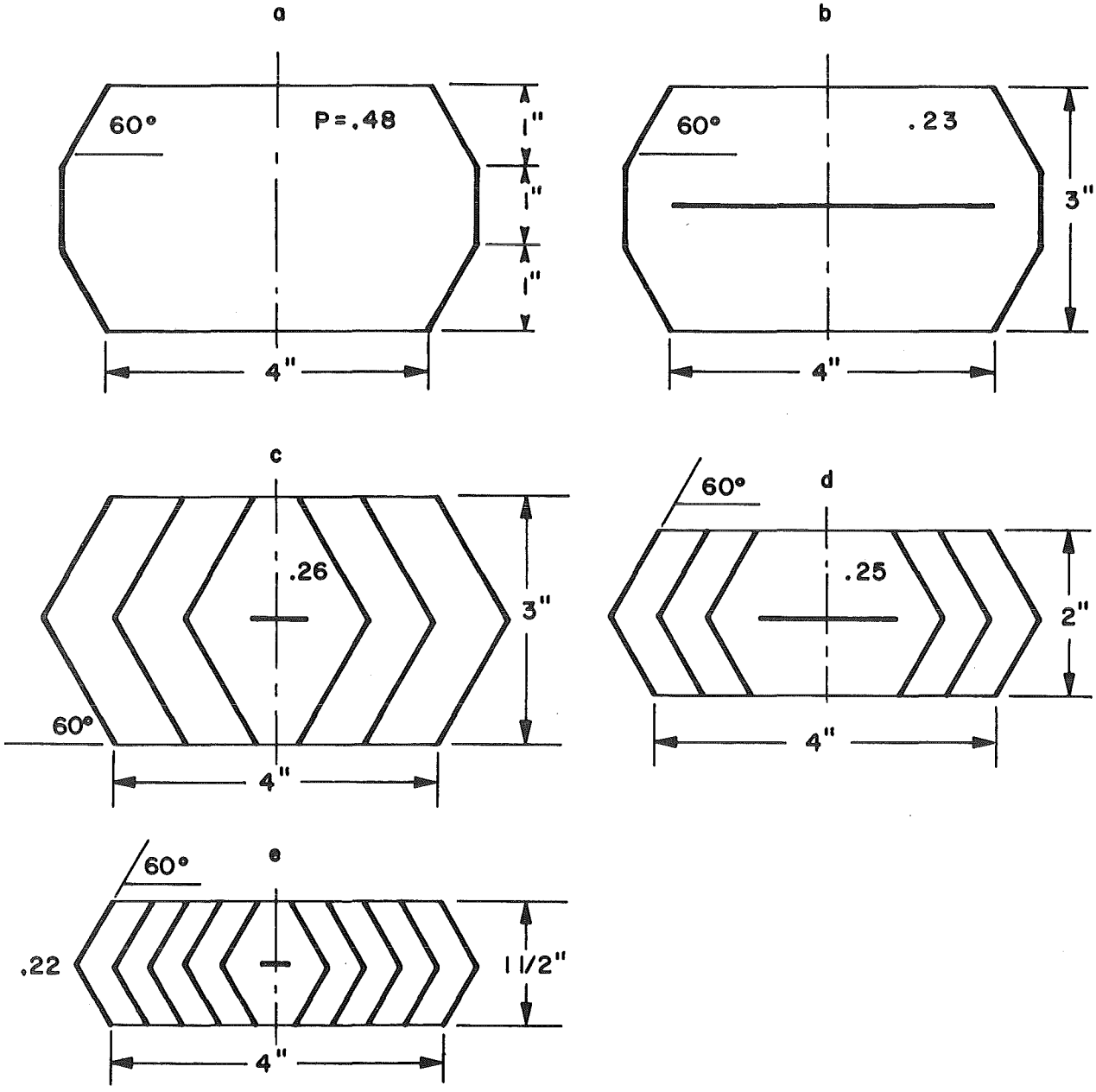


Fig. 10 Baffle Models

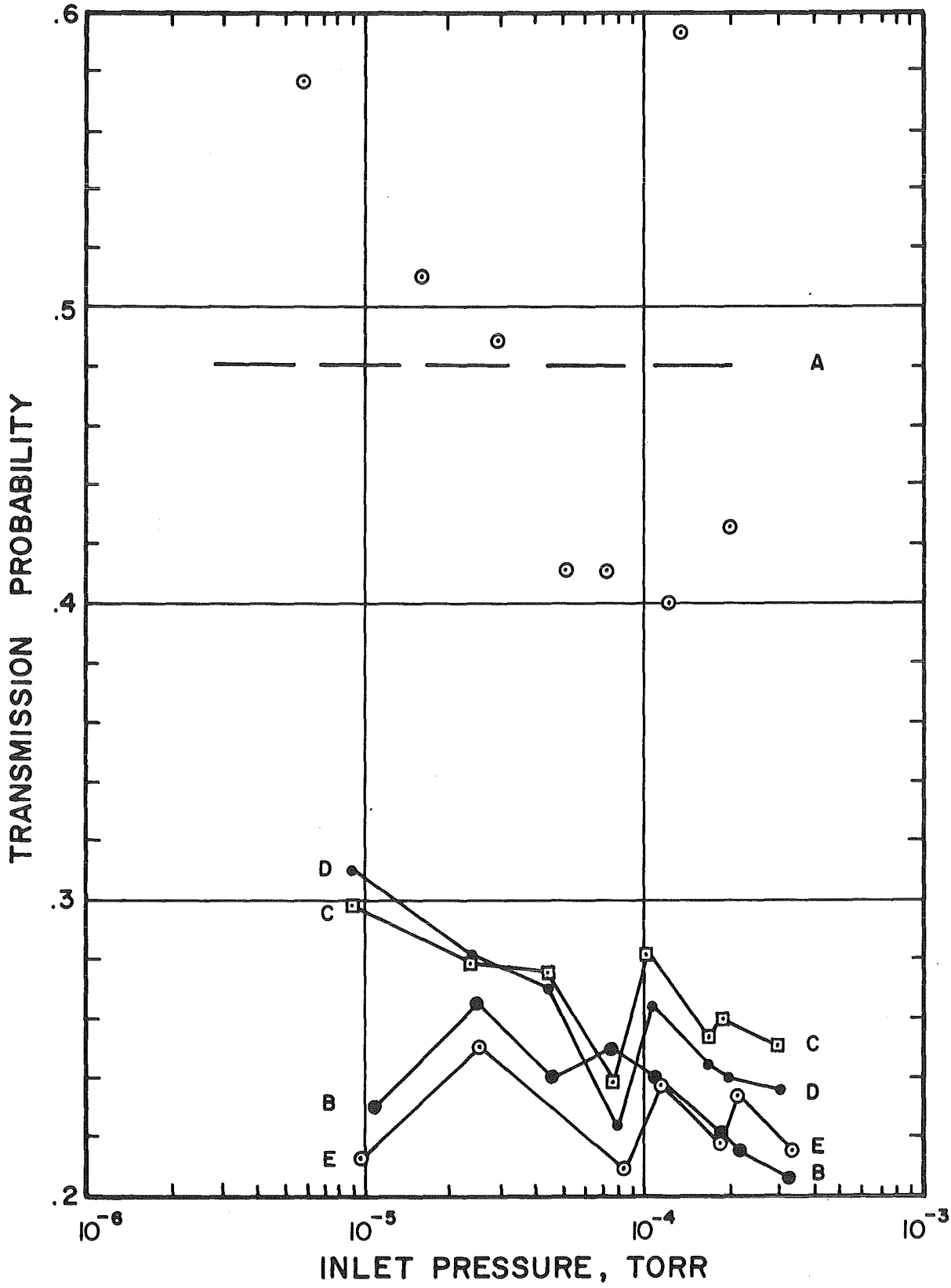


Fig. 11 Transmission Probabilities of Baffles Shown in Fig. 10

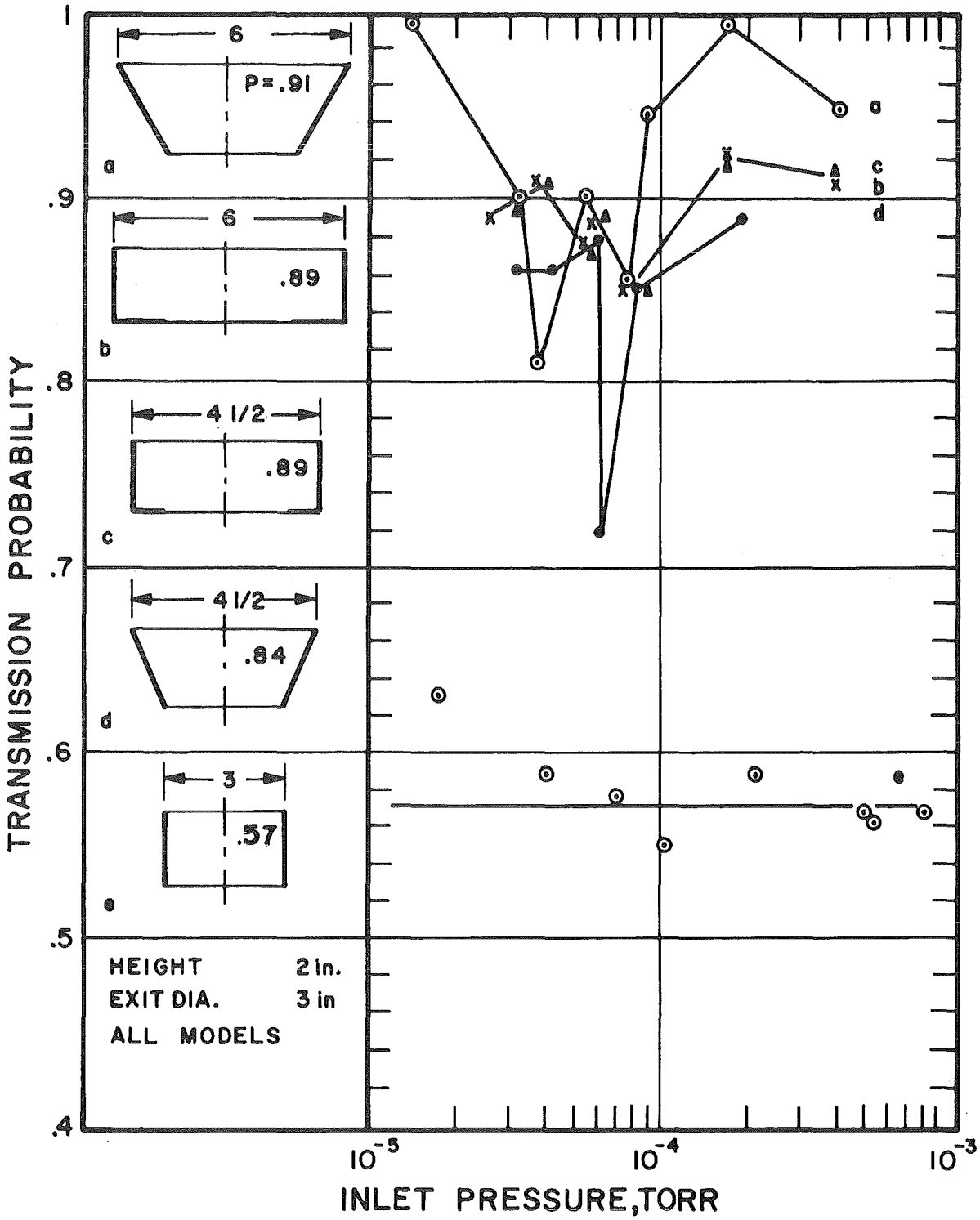


Fig. 12 Reducer Models and Their Transmission Probabilities

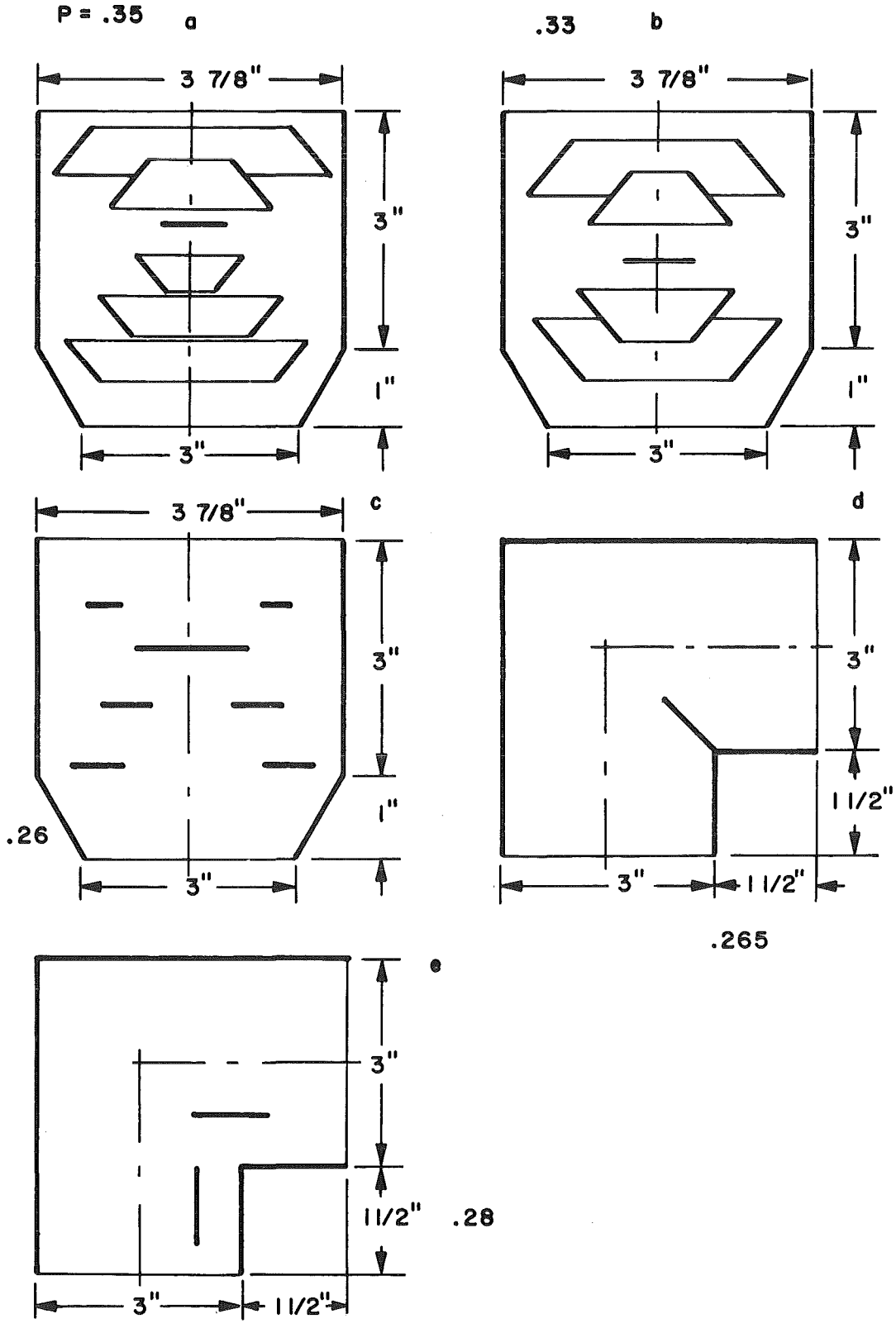


Fig. 13 Baffle Models

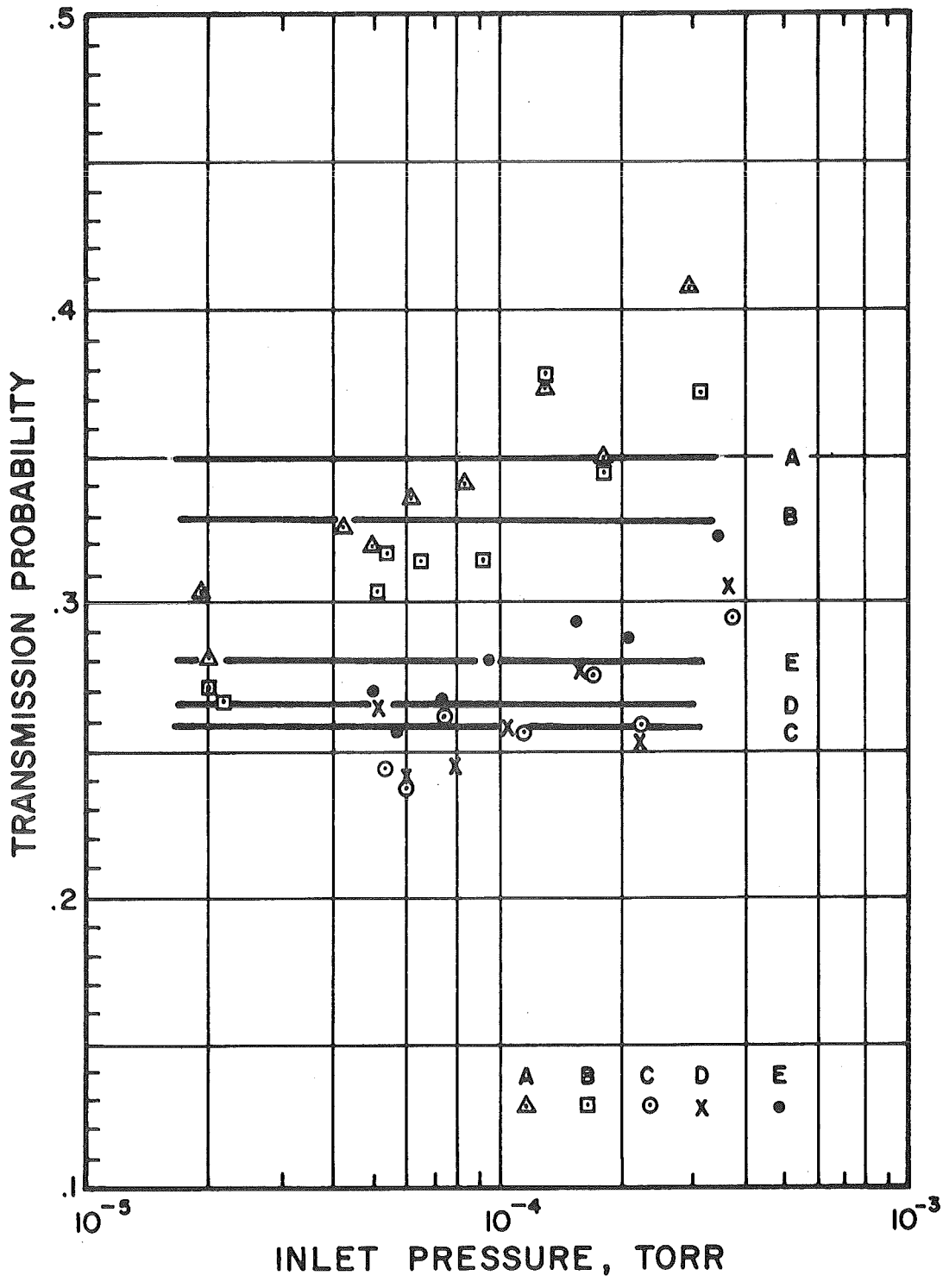
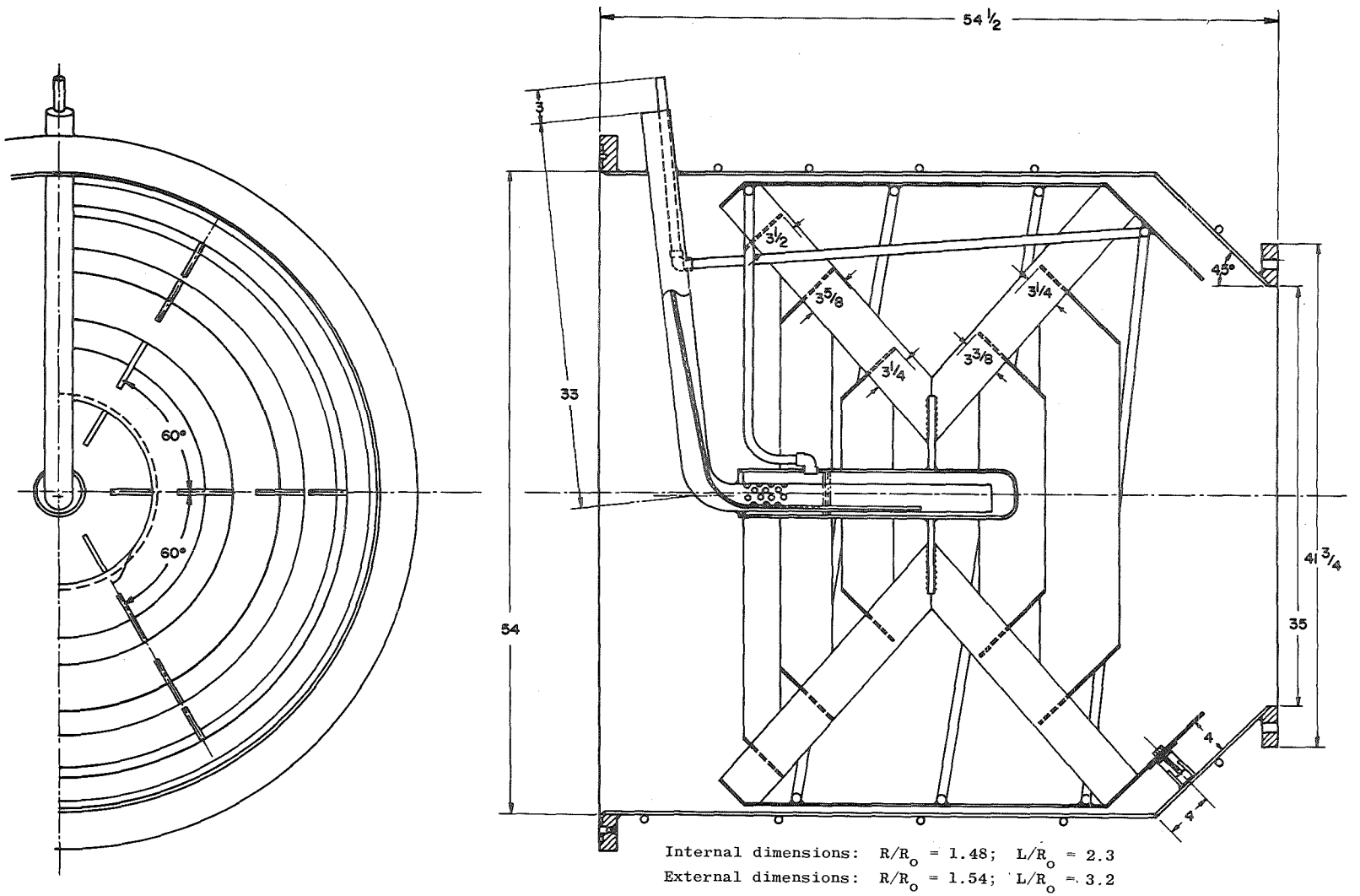


Fig. 14 Transmission Probabilities of Models Shown in Fig. 13



Internal dimensions: $R/R_o = 1.48$; $L/R_o = 2.3$
External dimensions: $R/R_o = 1.54$; $L/R_o = 3.2$

Fig. 15 Final Baffle Design for 35° Pump Station

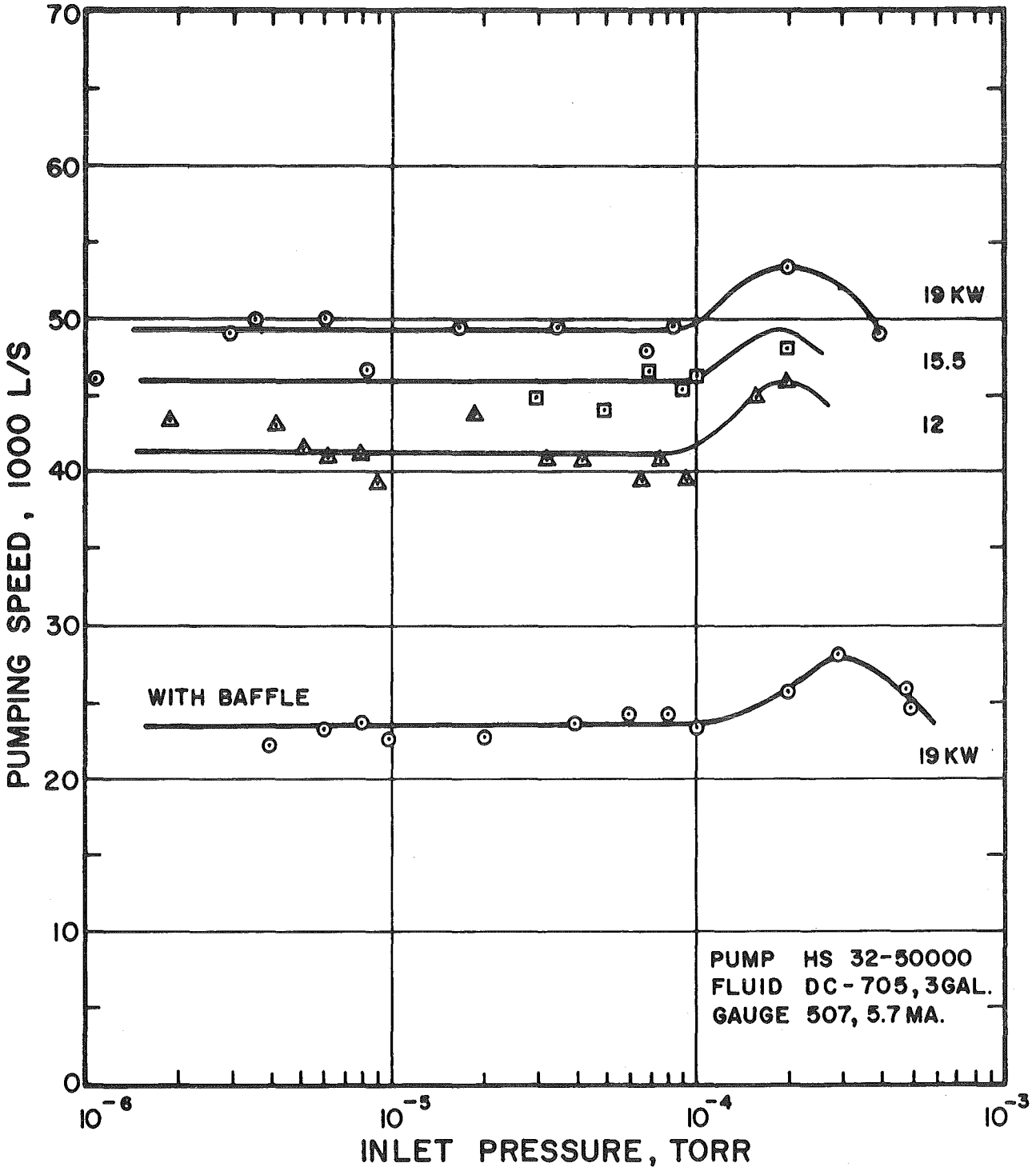


Fig. 16 Pumping Speeds of Unbaffled 35" Pump at Various Heat Inputs

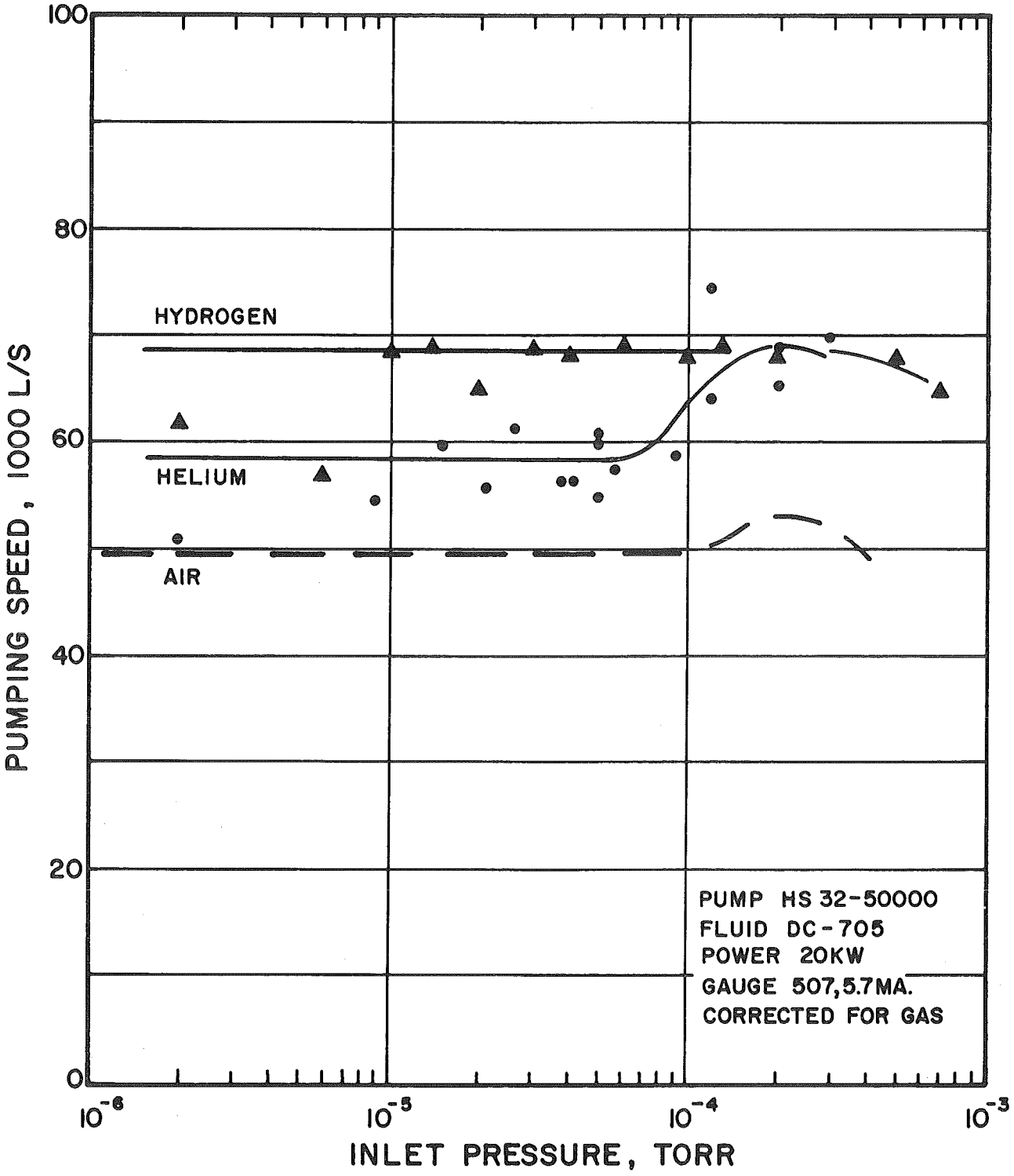


Fig. 17 Hydrogen and Helium Pumping Speeds for 35" Unbaffled Pump

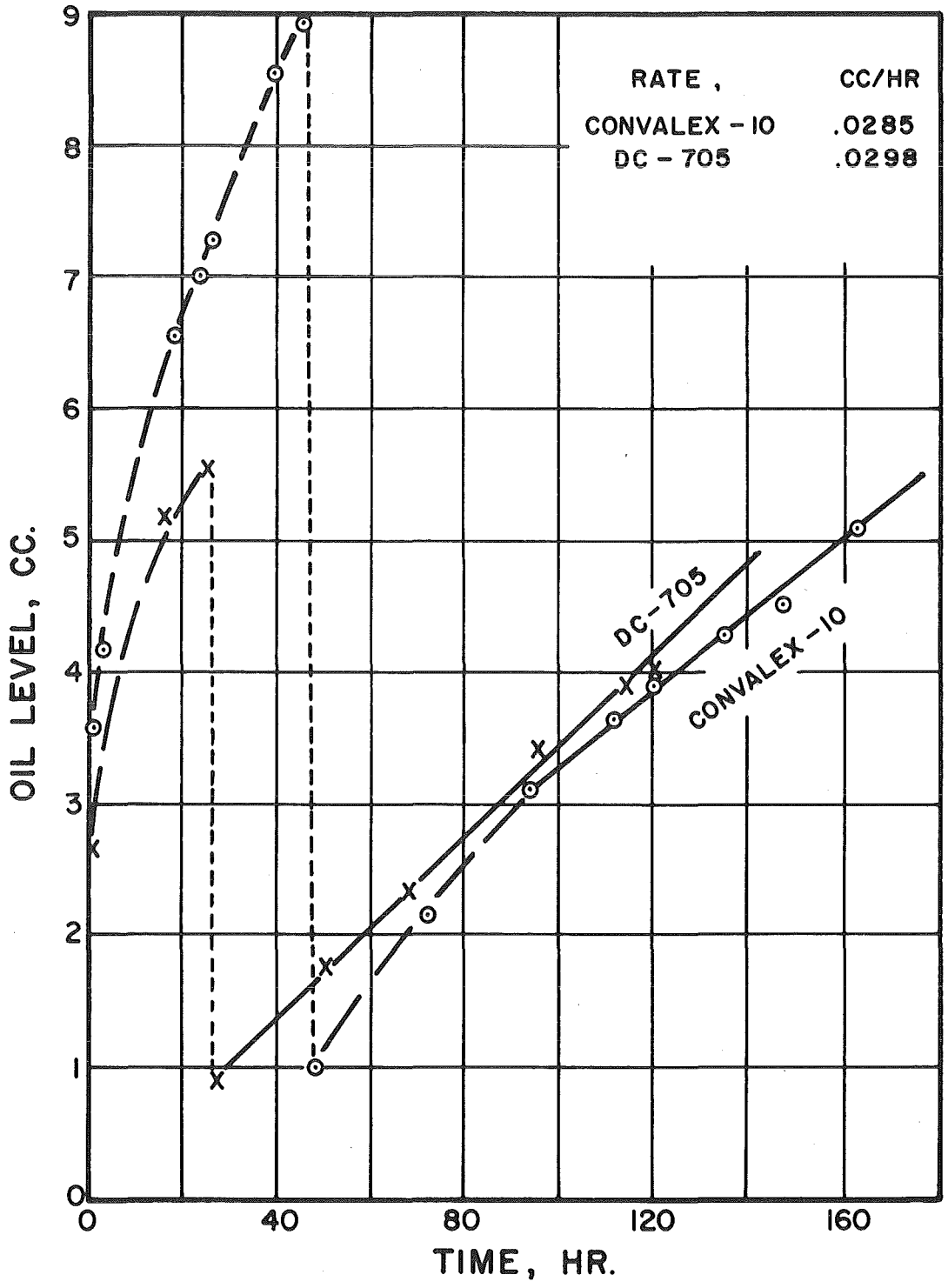


Fig. 18 Unbaffled (or Primary) Backstreaming Measurements for Two Fluids

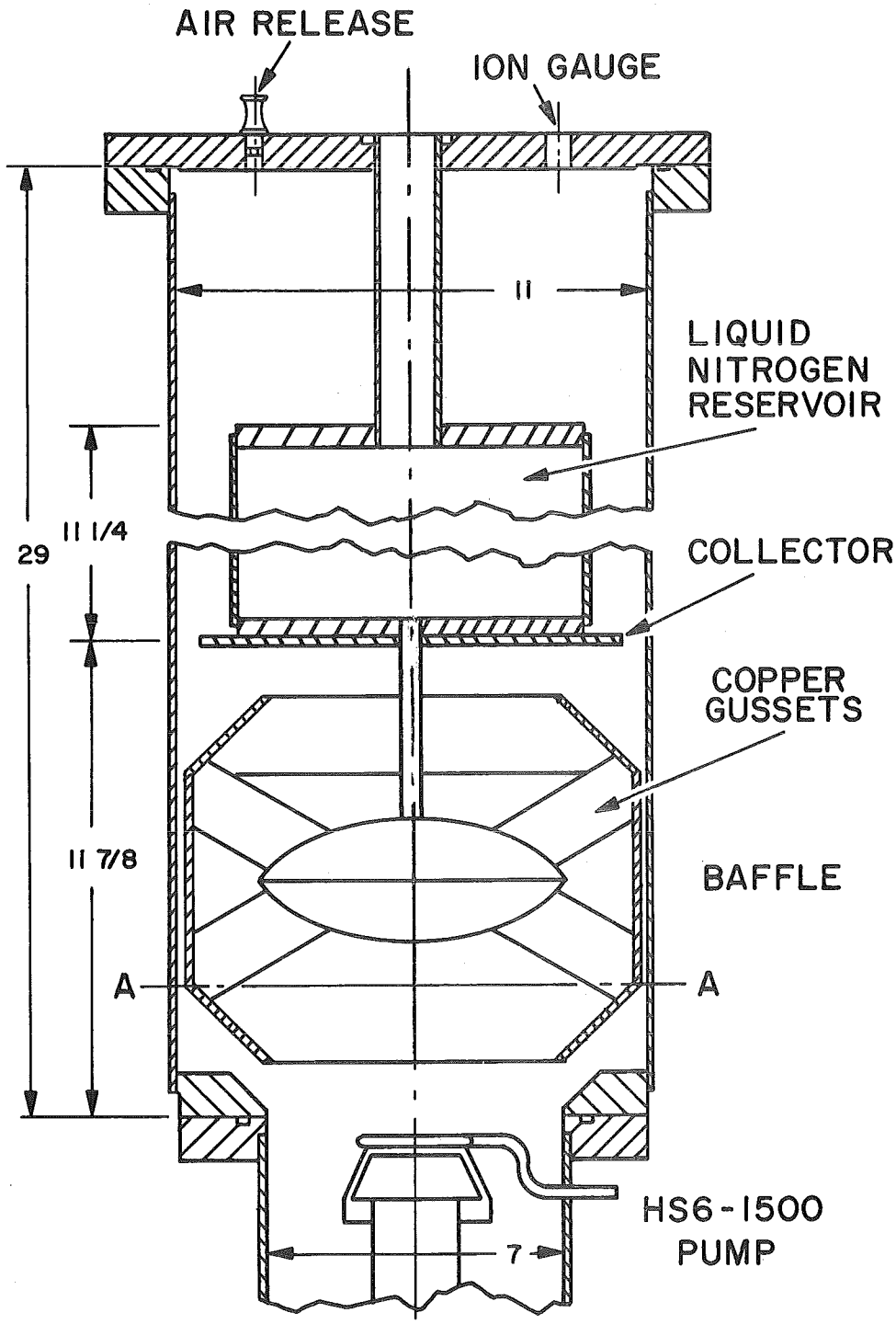


Fig. 19 Schematic, Comparative Backstreaming Dome for a 6" Pump

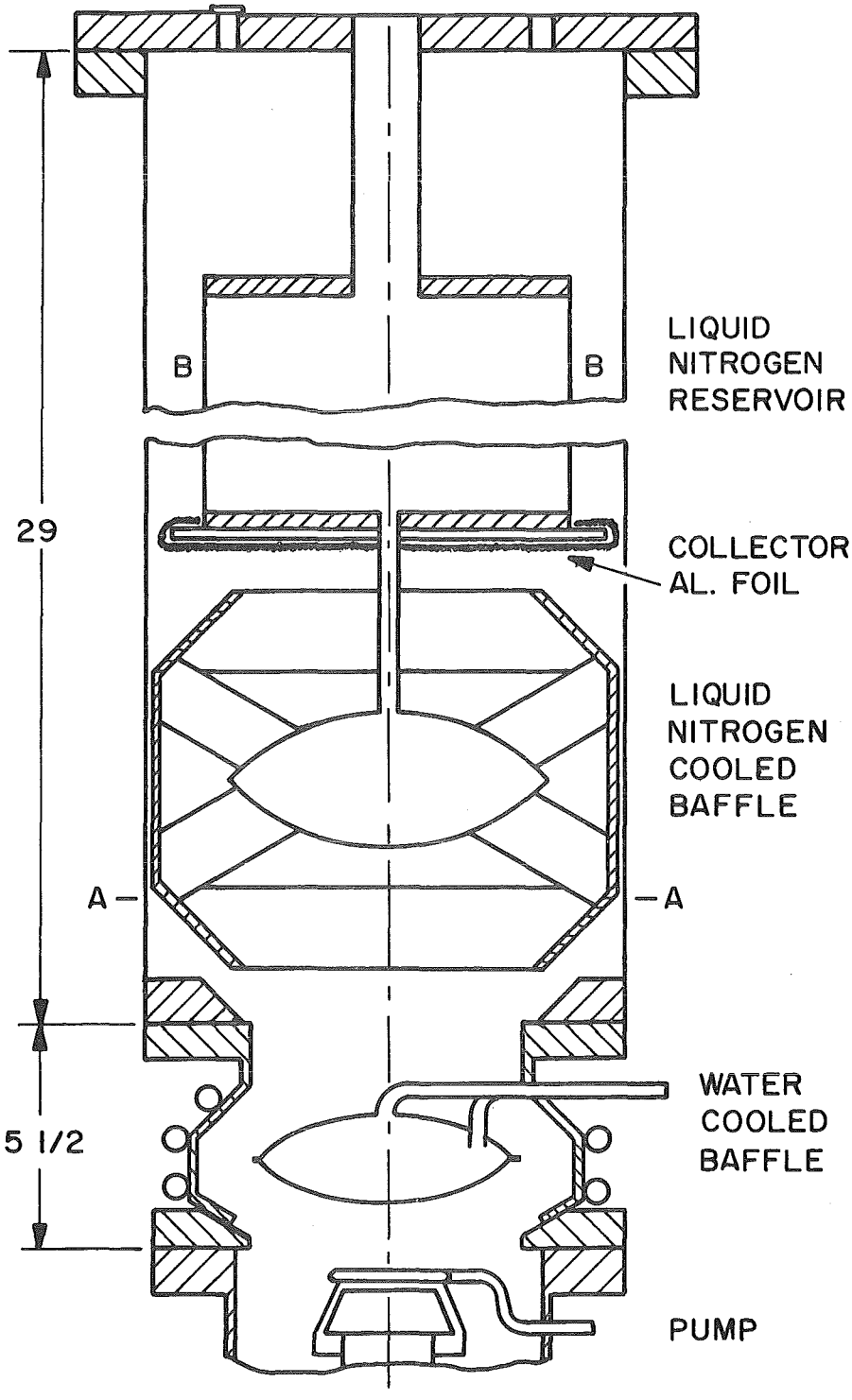


Fig. 20 Comparative Backstreaming Dome with Water-Cooled Baffle

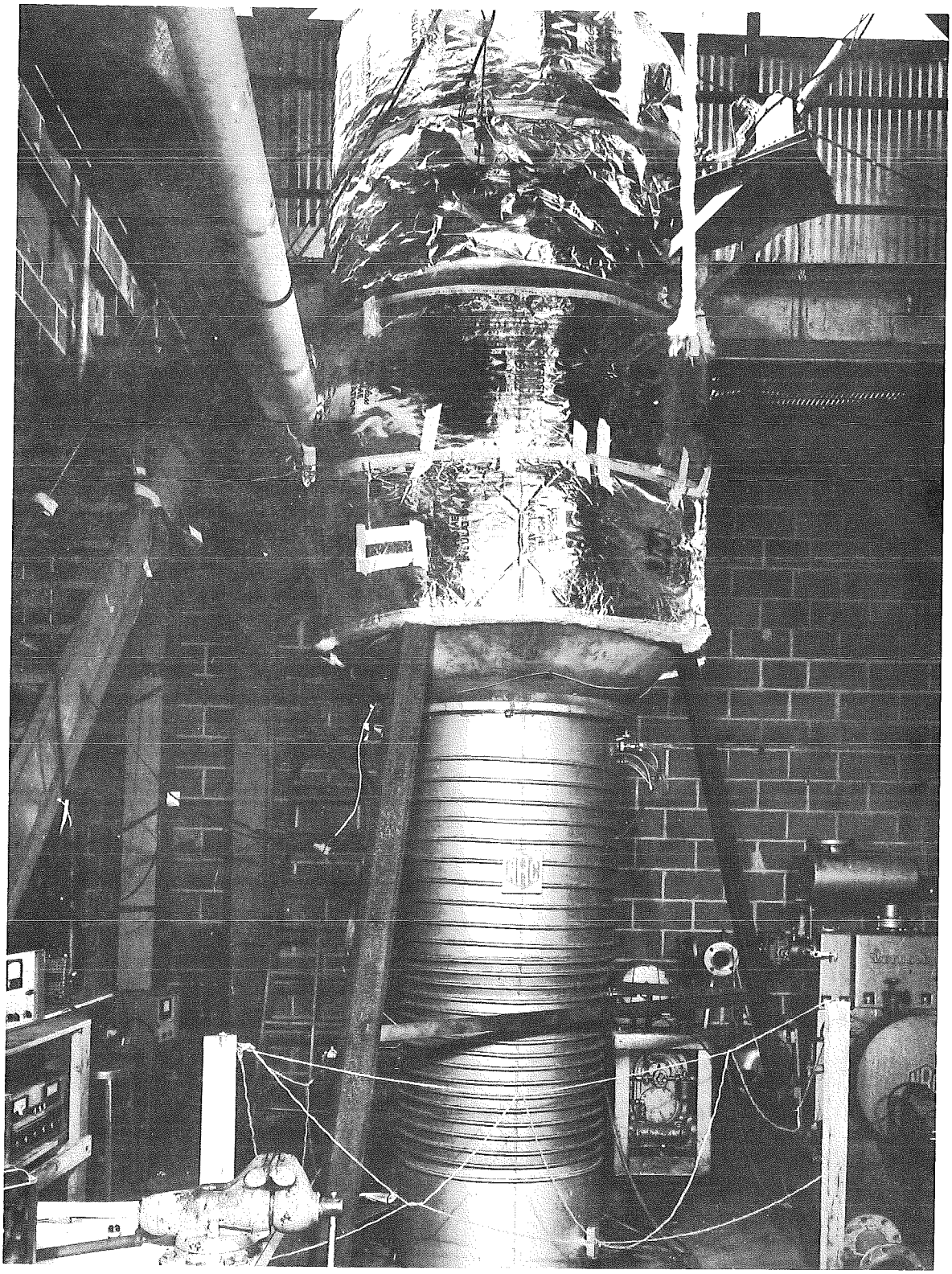


Fig. 21 35" Pump with Baffle and Dome

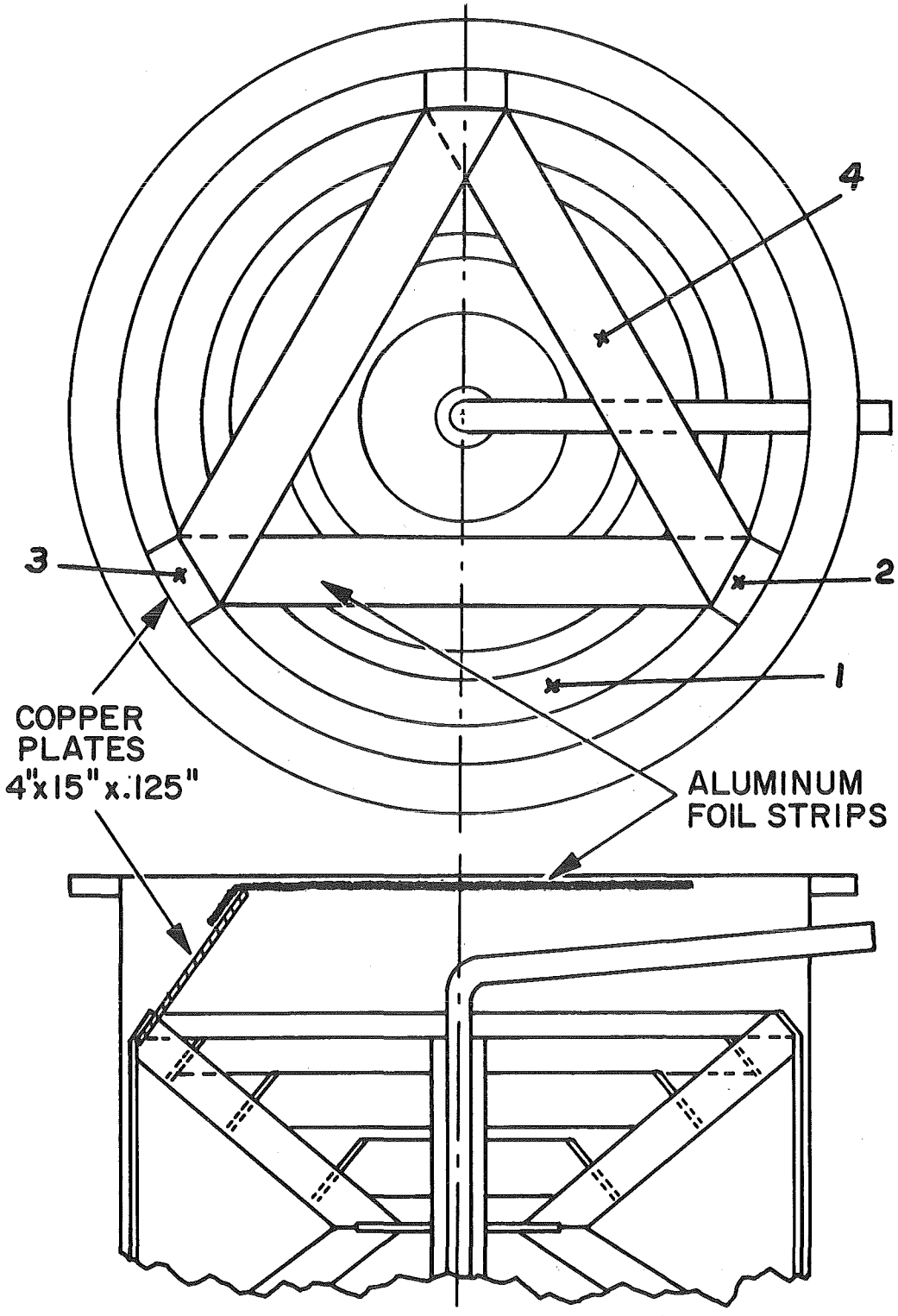


Fig. 22 Location of Thermocouples and Aluminum Foil Collectors

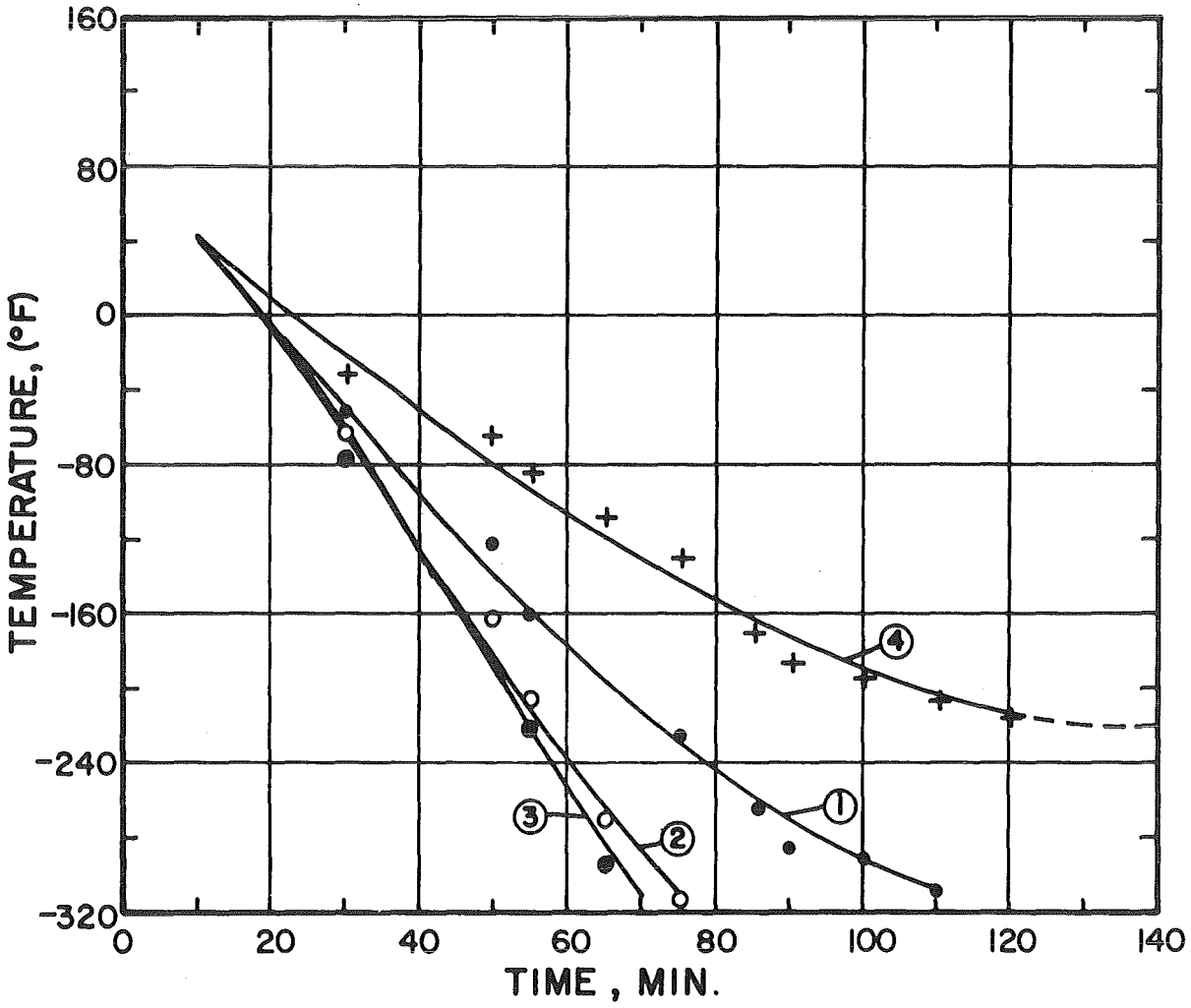


Fig. 23 Collector Foil Temperature vs Time

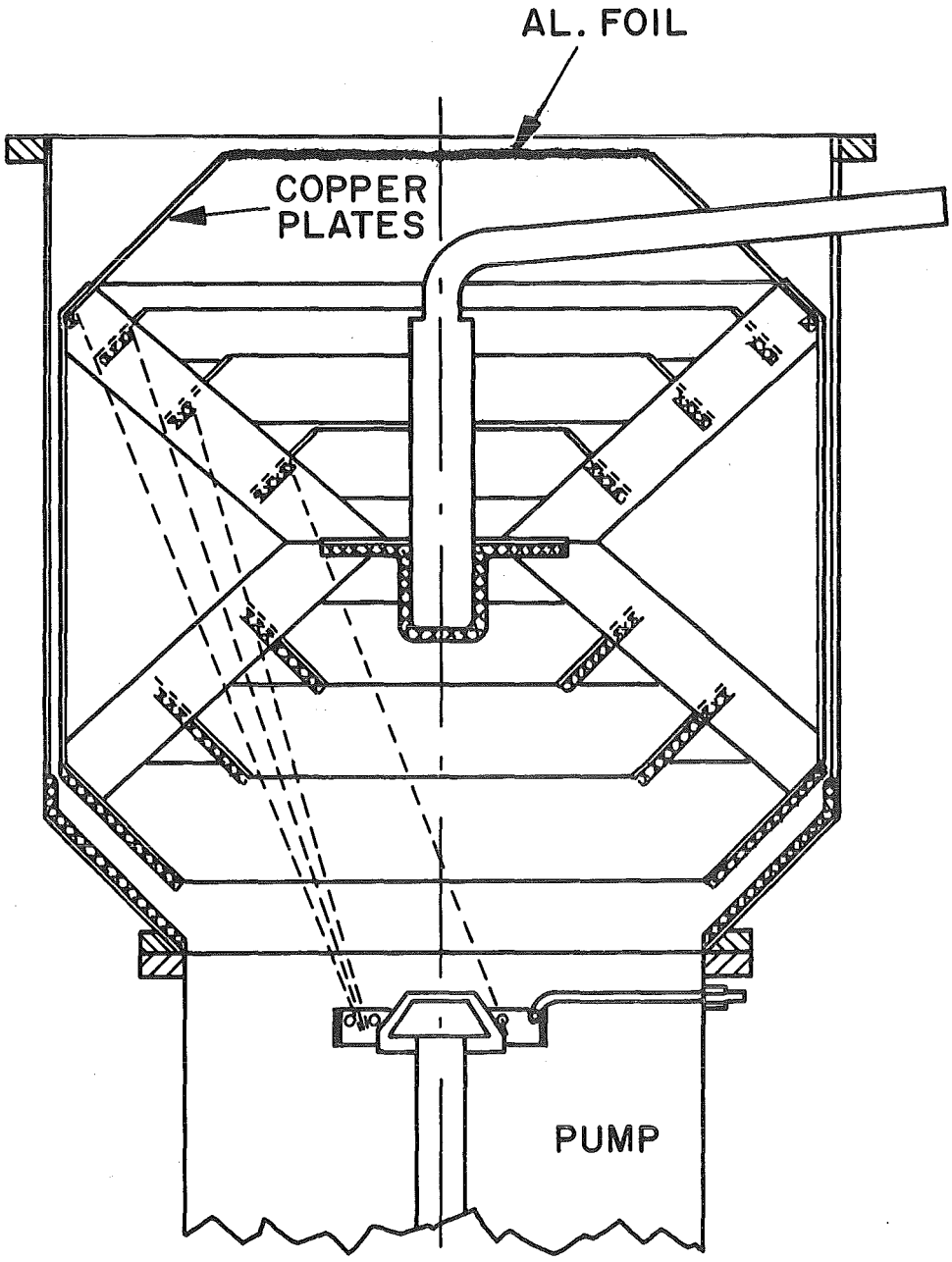


Fig. 24 Schematic of Baffle Showing Regions of Heavy Oil Deposits

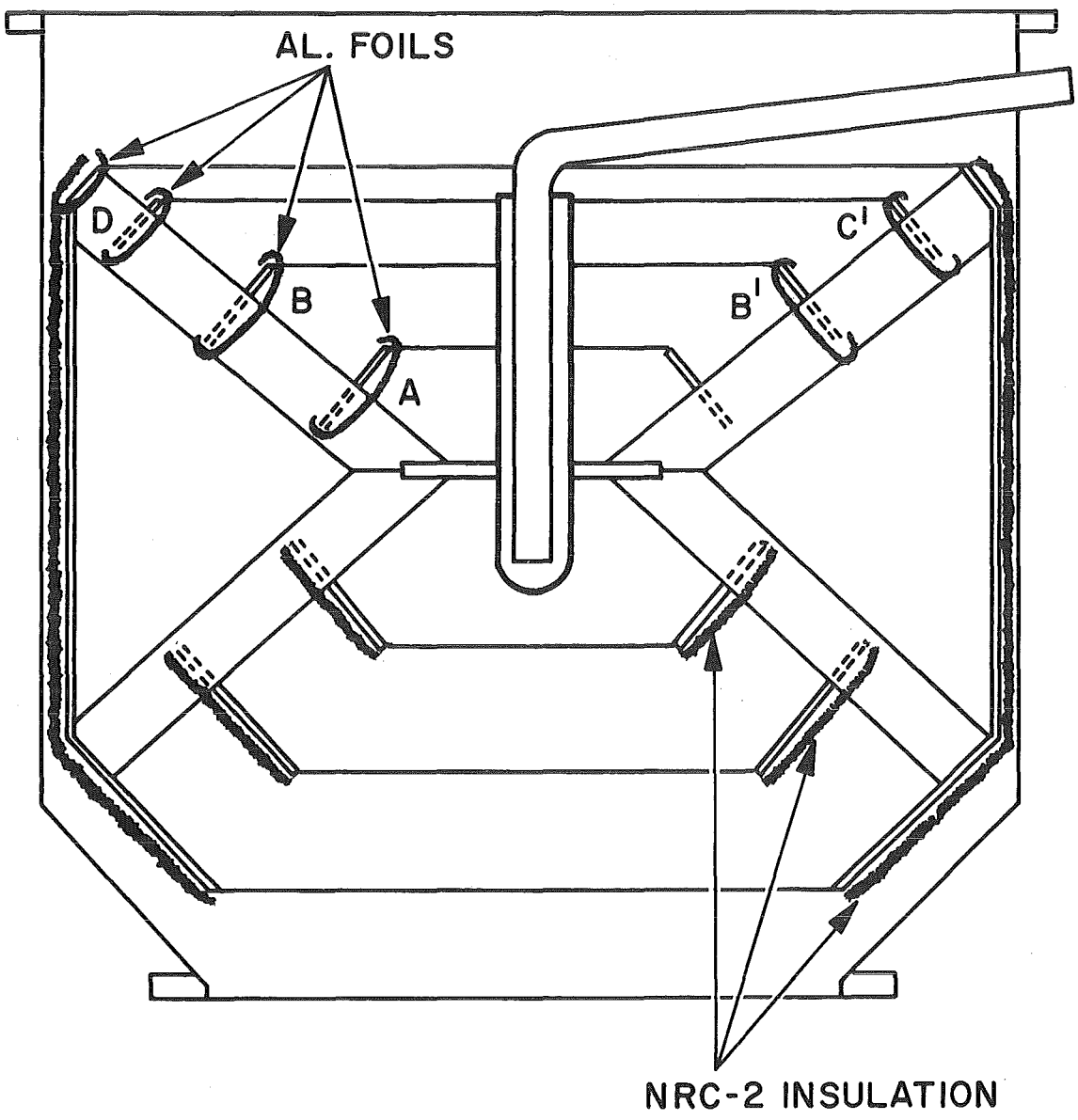


Fig. 25 Location of Collecting Foils for Oil Deposition Studies

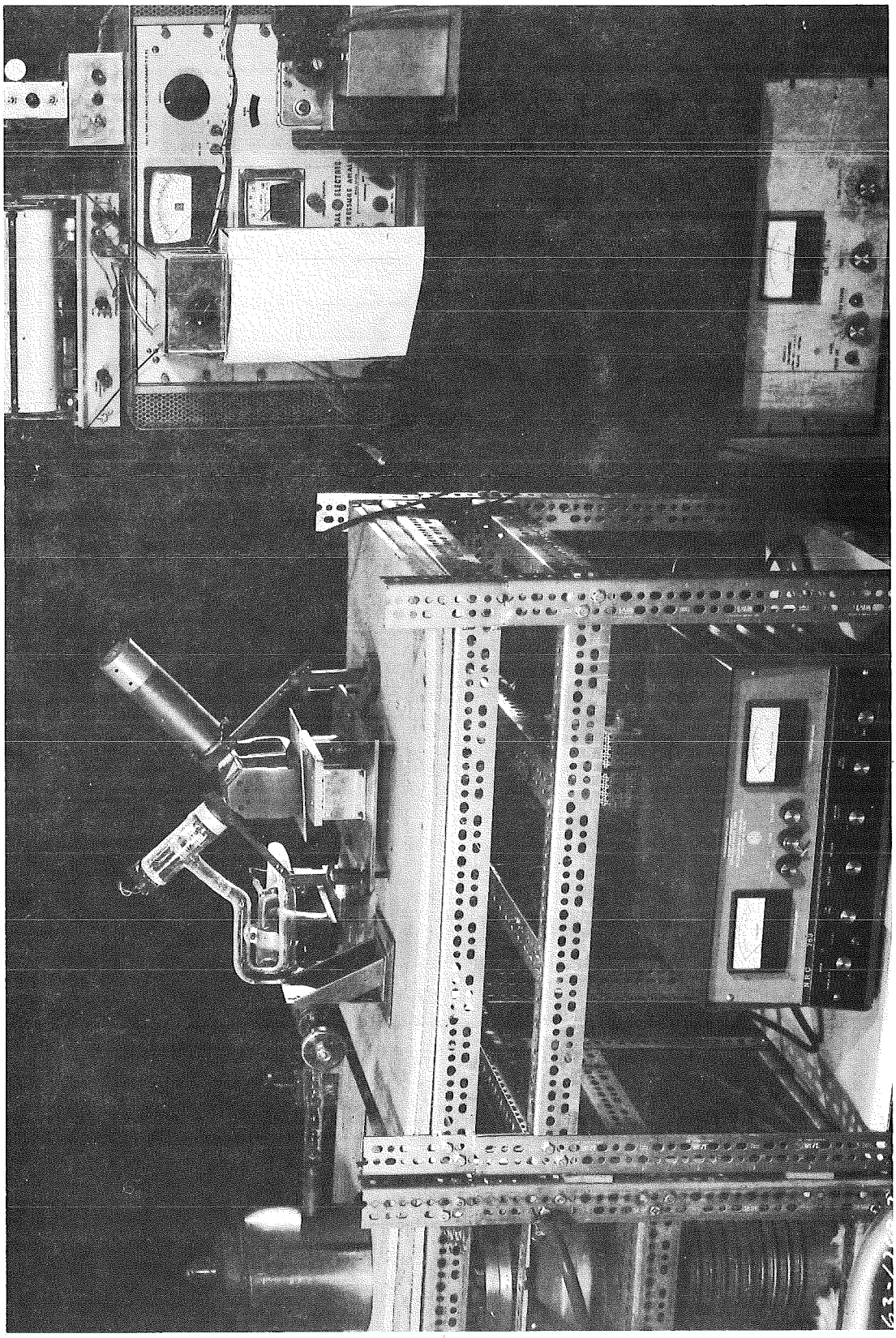


Fig. 26 Mass Spectrometer Residual Gas Analyzer

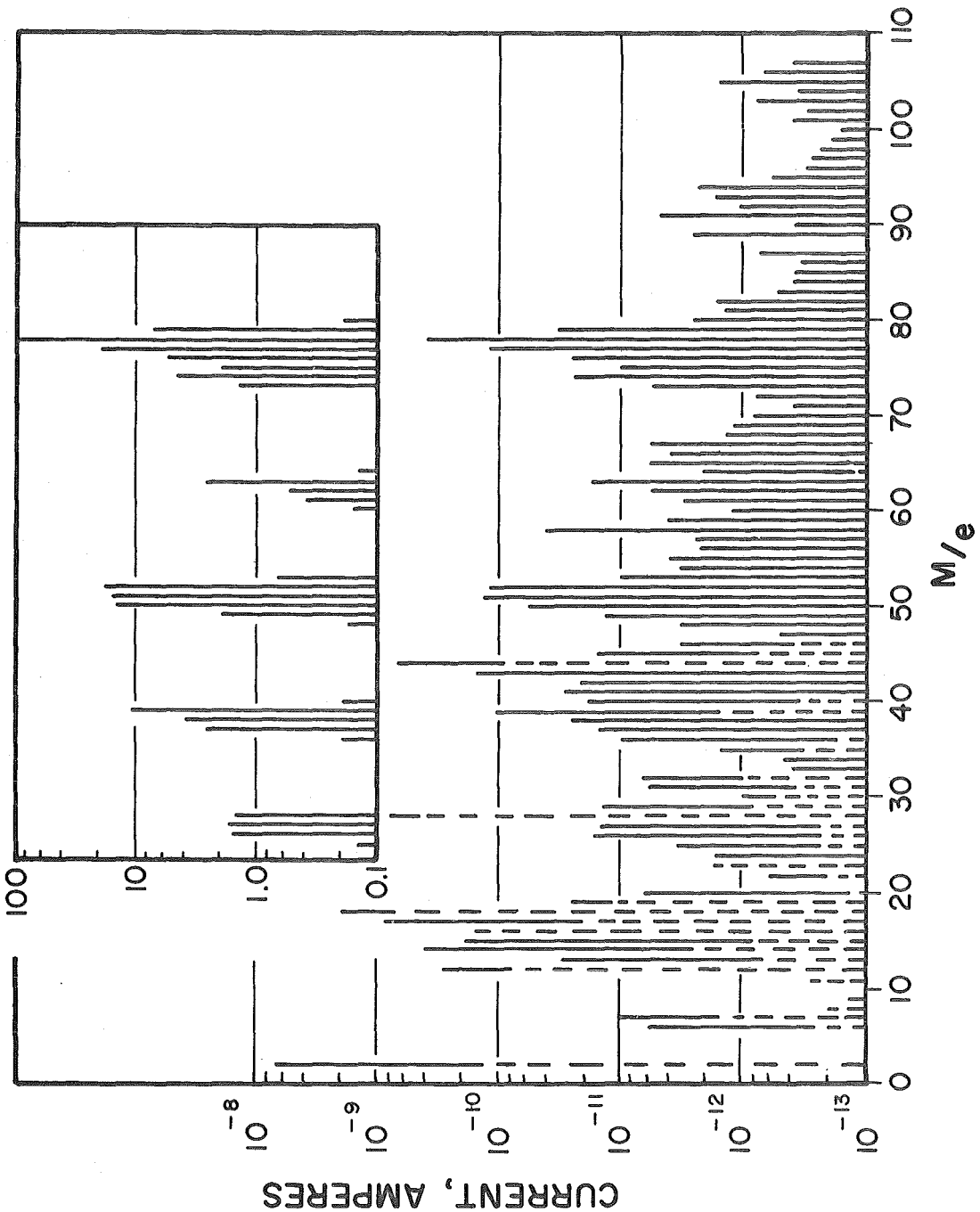


Fig. 27 Spectrum Taken Before and After Baking

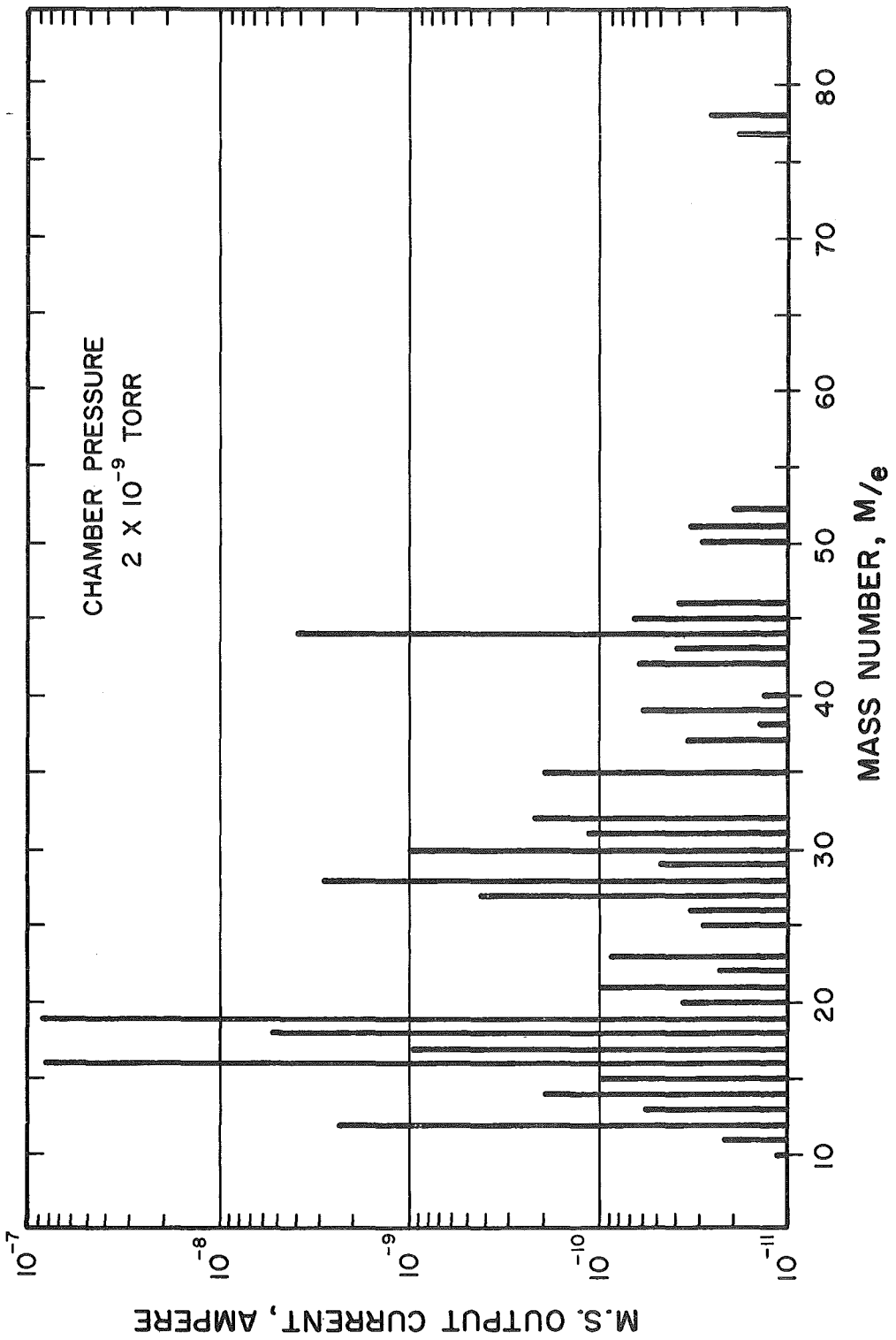


Fig. 28 Typical Spectrum, Residual Gas Composition, Test Dome Above 35" Pump and Baffle

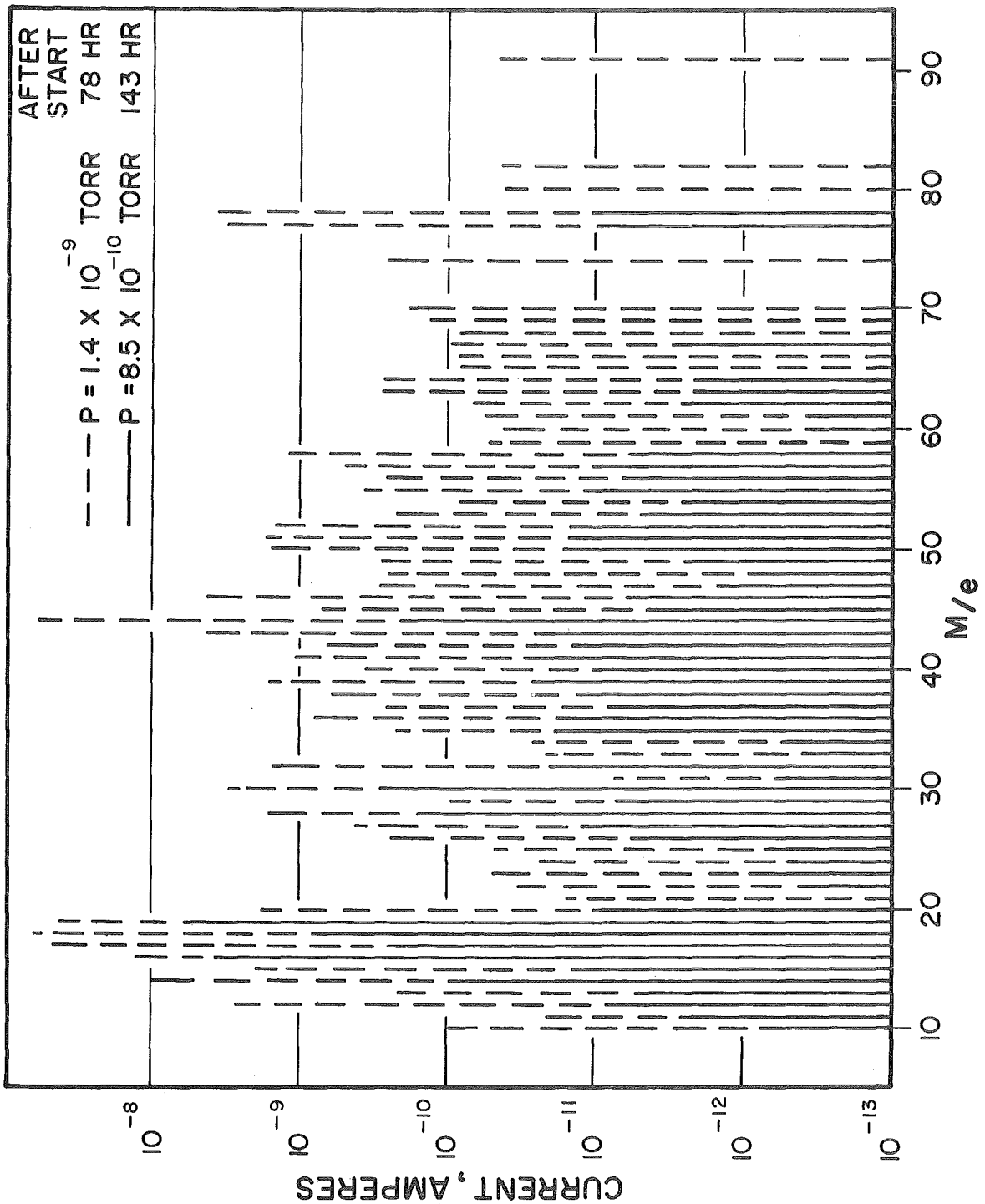


Fig. 29 Spectrum Taken Before and After Cleaning Mass Spectrometer Tube

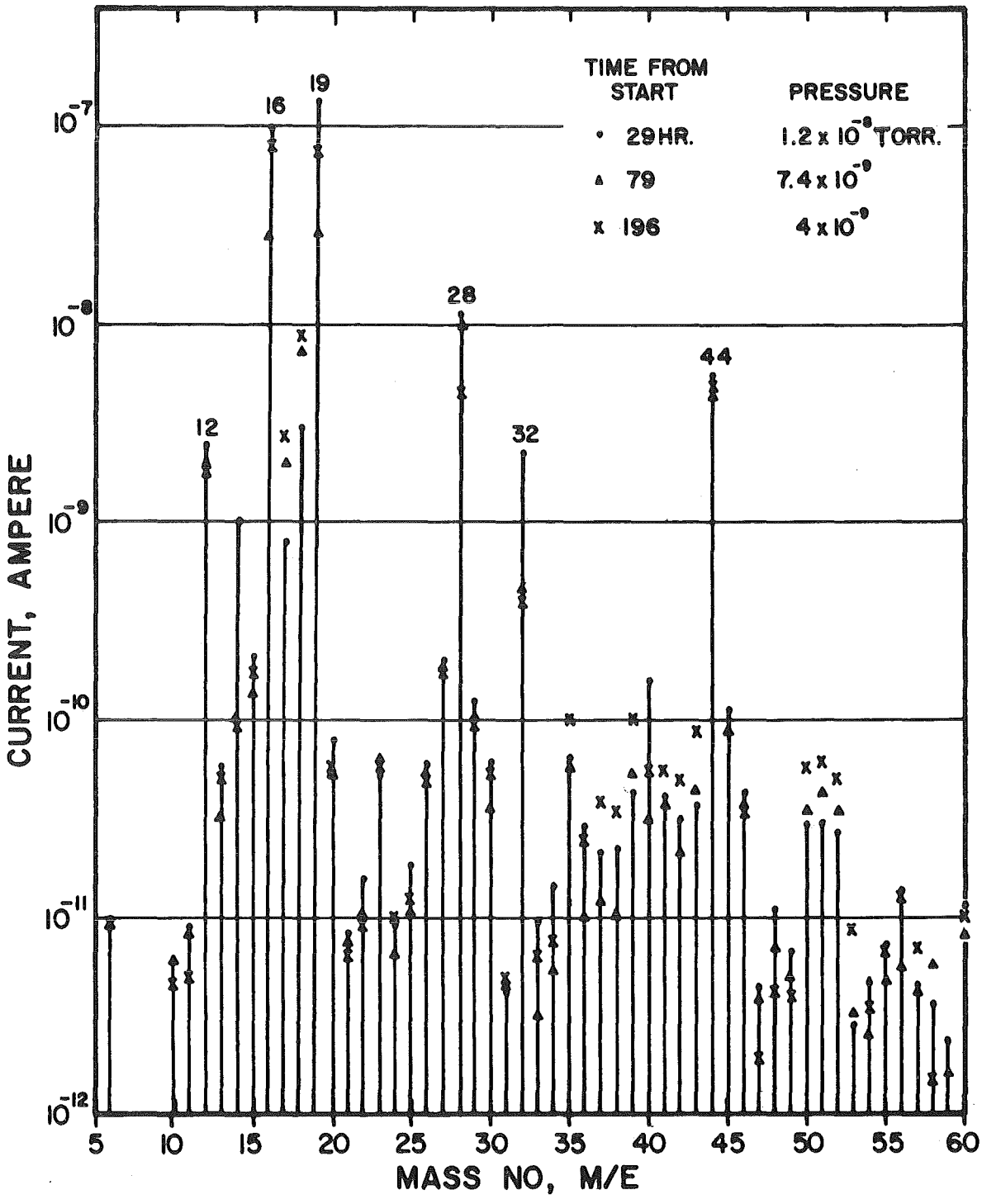


Fig. 30a Spectrum Taken During the 524-Hour Test, Low Mass Numbers

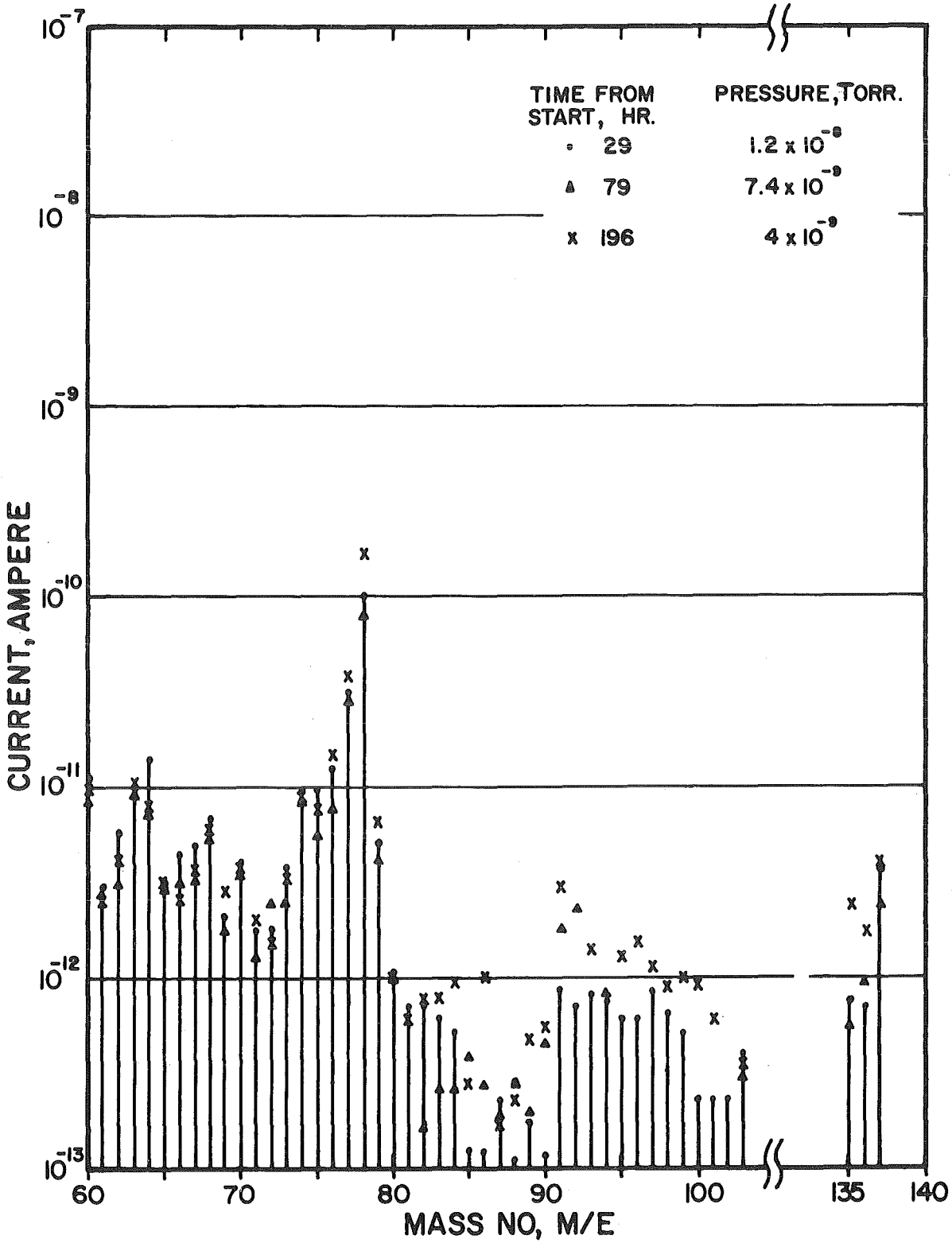


Fig. 30b Spectrum Taken During the 524-Hour Test, High Mass Numbers